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I

COUNTING ROOM EQUIPMENT AND PROCEDURES
AND SAMPLE PREPARATION

by

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Department of Instrumentation
and Health Physics

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COUNTING ROOM EQUIPMENT AND PROCEDURES

I. Description of Equipment

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The following are descriptions of some of the equipment currently used in the Health Physics counting rooms at the Laboratory. These descriptions are not complete but are intended as supplements to the manuals issued by the manufacturers. Some of these units have been modified to fulfill special needs. The details of these modifications are presented below.

A. Scintillation Counters

Scintillation counters are used for counting alpha particles. These utilize an RCA 5819 photomultiplier tube. The sensitive region of the counter is produced by coating the end of this tube with a silver activated zinc sulfide phosphor of about 8 mg/cm^2 thickness. The output of the photomultiplier is fed to a preamplifier using a 6AG5, and the output of this is then introduced into the input circuit of a conventional scaling unit. If the cable is not too long, no additional amplification at the scaler is necessary.

The sample holder currently in use with this instrument consists of a round plate of aluminum containing a sample hole 5.08 cm in diameter and 1.27 cm deep. The sample hole is near the edge of the upper face of the plate. This plate is positioned by a brass stop which limits its rotation in the following manner. In one position the sample hole is outside of the counter. By rotating the plate the hole slides into its second position directly under the sensitive area of the counter. (See Figure 1, 2). A lucite plug containing a depression the size of a standard planchet is made to fit securely into this hole, thus placing the sample closer to the counter and providing for greater efficiency for samples with low counting rates.

These counters operate at about 1100 volts. The efficiency of a unit as described above is about 25% for a sample on a standard aluminum planchet (1-1/4" diameter). The dead time is comparable to that of the scaler. Usually the mechanical register is the limiting factor in the counting rates which the system is capable of handling.

These counters appear to be very stable, insensitive to humidity, free from spurious counts, and completely free of microphonics. Another desirable feature is the low background obtained, 0.1 to 0.3 counts per minute.

B. End Window Beta-Gamma Counters

Victoreen or Nucleonics mica end-window tubes¹ are used in vertical lead shields 1-1/2" thick. The tubes are mounted in lucite frames containing a number of shelves for inserting a sample holder at various distances

from the window. The sample holders are pieces of aluminum which are made to fit the shelves and contain depressions of the appropriate size for the planchets generally used. Adaptors can easily be made of lucite for any other reasonable size sample.

A Geiger-Muller counter has the following characteristic curve.

The region AB is known as the geiger region. In this region the counting rate is substantially independent of voltage. Point A is the threshold of the geiger region and is the voltage at which the amplification factor becomes independent of the amount of primary ionization and all discharge pulses attain equal amplitudes provided the separation between pulses is sufficient to allow full recovery of the tube.

These Geiger-Muller tubes operate at about 1200-1400 volts. Their average lifetime is two to four months. Although the scalars are left on continuously, the high voltage is turned down at night to prolong the life of the tube. These tubes give backgrounds of about 20 counts per minute and have a dead time of about 4×10^{-4} seconds. It is important to provide as short a cable as possible between the tube and the scaler. Cable RG-59/U or RG-62/U is recommended to reduce capacitive loading of the input circuit. Electronics, and Nuclear Instrument and Chemical Corporation scalars (Figure 3) are used with these tubes in our counting room, however, any standard scaler is equally as good. The scalars are modified for either predetermined time or predetermined count. These scalars are quite reliable and are easily serviced.

C. Precipitron Beta-Gamma Counter

A cylindrical glass thin window Geiger-Muller Tube is placed in the center of a horizontal lead shield for use in counting precipitron samples. These are samples of dust which have been electrostatically precipitated onto an aluminum sheet rolled to form a cylinder. The lead shield has a wooden lining of the proper size so that the precipitron sample just fits into it and is held with all parts of its surface equidistant from the tube.

The unit provides a convenient method for counting precepitron samples of the type mentioned. However, it has the disadvantage that its

counting efficiency* is extremely difficult to obtain. This efficiency could be found by counting a point source placed in several positions and then integrating over the entire area of the sample, or by preparing a source of known disintegration rate having the same dimensions as the sample to be counted. The efficiency varies widely for different particle energies.

D. Autoscaler Beta-Gamma Counter

The Tracerlab autoscaler uses Tracerlab or Nucleonics mica end-window tubes of the plug-in type in a vertical lead shield 1-1/2" thick. This shield has a horizontal shelf upon which are mounted two aluminum planchets. This shelf slides back and forth so that one or the other of the planchets is under the counter window. The scaler may be set for predetermined count or for manual operation. This unit is used primarily to count smears since the planchets in use do not fit into the shelves provided. The unit has a background of from 25 to 30 c/m.

E. Continuous Flow Proportional Counter

The continuous flow proportional counter consists of a hemispherical chamber the collector of which is a fine wire loop suspended from the top of the hemisphere. The bottom of this hemisphere is a flat platform on which the sample is placed. It is contained in a shelf which slides on ball bearings so that it may be pulled out, the sample inserted, and the platform pushed back into position under the hemisphere. When it is thus in position the turning of a knob on the front of the shelf raises the platform on which the sample has been placed until it makes contact with an O-ring rubber gasket around the lower edge of the hemisphere. This seals the chamber from the air.

The chamber must then be purged to free it from all air. This is done by closing a switch on the solenoid valve which is on the top of the scaler. This provides for an increased rate of flow of the gas through the chamber. A minimum of two minutes is required to thoroughly purge the chamber at a convenient rate of flow. If the chamber is not entirely purged, the maximum number of counts will not be obtained. After purging, the switch is restored to original position which provides a decreased rate of gas flow just sufficient to keep a positive pressure within the chamber. The sample is now ready for counting.

This counter assembly is available as a unit from the Nuclear Measurements Corp. and contains the chamber, sliding shelf, solenoid valve, and timer all within the scaler. However, since suitable scalers and timers were on hand only the chamber and shelf assembly and the solenoid valve were purchased and used with a Nuclear Instrument and Chemical Corp. model 162 scale of 128 scaler (Figure 4a). This scaler was found to be desirable because it contains sufficient amplification for use with proportional counters. This scaler was modified for predetermined time using a Gralab

*For definition see II-C.

timer by inserting a relay as shown in Figure 4b, and the solenoid valve inserted as in Figure 4c. The gas mixture used is 90% argon and 10% methane (P-10 mixture).

The sample platform has a diameter of 2-1/4" and may, therefore, be used to count samples of a variety of sizes. However, the maximum sample height that will fit into the chamber is 1/8". The chamber assembly is mounted separately from the rest of the unit in a lead shield of 1-1/2" thickness. The shield, made especially to house this apparatus cuts the background to about 20 counts per minute.

If pulse height is plotted as a function of the applied voltage, the following curve is obtained

In regions A and B avalanche ionization does not occur. Region C is the proportional region where avalanche ionization exists near the central wire. D is the region of limited proportionality. Here the amplification factor is about 10^5 to 10^7 as avalanche ionization occurs farther from the center wire. The geiger region, E, has an amplification factor of about 10^8 . F is the region of continuous discharge.

This type of counter operates in the proportional region. In this region avalanche ionization occurs but does not spread. Instead it is restricted to the vicinity of the primary ionization. Therefore, the size of the pulse is proportional to the number of primary ions. Since alpha particles have a greater specific ionization than beta particles, it is possible to discriminate between the two types of particles. Since an alpha particle produces more primary ions, a lower collecting voltage is necessary to produce an output pulse of a given size. The operating point for alpha counting is about 1300 to 1500 volts at maximum gain. For beta counting it is 2000 volts. The alpha plateau is large, extending for about 350 volts. The beta plateau is shorter and has a greater slope. The plateau lengths are a function of the gain settings used.

The counting efficiency as determined for alpha counting is about 50%. For beta counting, the efficiency for a radium D and E standard source is about 55 to 60%. When corrected for backscattering from the silver palladium backing of the radium D and E standard to aluminum, usually used with samples, this figure is reduced somewhat. These efficiency figures may vary a good deal. The values given represent the lower limit of the range of efficiencies found in the past.

The geometry is fairly constant over most of the area of the sample platform; however, it decreases about 5 to 8% near the edges (Figure 5).

The dead times for the units in the counting room as measured with two point sources are about 4×10^{-5} sec.

This type of counter has the advantage that the sample is placed within the sensitive volume of the counter thus making it possible to count more particles of lower energies than is possible with Geiger-Muller tubes. Also, background counts due to the presence of radon or thoron in the air are eliminated because of the continual flushing of the chamber.

Extreme care must be taken to keep the chamber and the surface of the rubber gasket clean so that an airtight system is maintained. It is also advisable to keep the sliding shelf clean and oiled to provide ease in operation. Frequent cleaning is also desirable since the presence of dust particles may cause spurious counts to occur. Sharp points on the sample or sample holder must also be avoided as this will distort the electric field. It is also necessary that the sample and any absorbers that are used be well grounded, since the accumulation of a floating charge will cause undesirable effects. Extreme care must be taken in counting loose samples since the flushing procedure may easily cause contamination of the counter.

Figures 4g and 4h show two views of this counter. There are three such counters presently available. One unit has been provided with a means of recording the counting rate as a function of time to facilitate decay studies. (See F-4 below).

F. Auxiliary Equipment for Use with the Counters

1. Predetermined Time Assembly: Most of the counters now in use operate with predetermined time. That is, when a clock is set for a given length of time, the counter begins operation. At the end of this time the counter stops automatically provided the stop-count switch is left in the stop position. Most commonly in use is the Gralab one-hour timer. Employed less frequently are the Eagle and Microflex timers. The latter two are less accurate for short periods of time. The Microflex timer has the added disadvantages that it must be readjusted every time the length of count is changed and does not indicate how much time remains in a counting period.

The modification of the scaler for the timer consists of a double-poled relay controlled by the timer and connected in parallel with the "stop-count" switch of the scaler.

2. Predetermined Count Assembly: The Nuclear Instrument Corporation's model 163 scaler (Figure 6) may be used for predetermined count. The scale selector may be set to operate on a scale of 2, 16, 32, or 64. Any one of these may be multiplied by 10, 100 or 1000, thus giving a large choice of selected counts. This scaler is operated with a Standard timer. After the dials are set for the desired predetermined count, counting is initiated by the "stop-count" switch. This action also starts the timer. When the predetermined number of counts is reached counting stops and the timer is automatically turned off. The advantage of this method of counting is that for a constant number of counts the error in percent is constant and thus uniform statistics may be obtained. A disadvantage is the tedious arithmetic necessary in order to subtract the background.

3. Automatic Sample Changer: An automatic sample changer has been developed to facilitate the counting of large numbers of similar samples. The unit now in use is an improved version of the original model². The associated counter unit consist of a mica end-window G.M. tube, a regulated high voltage power supply, a ratemeter, and an Esterline-Angus recorder.

The sample changer is operated by a small motor which rotates an arm to which is connected a drive rod converting the rotary motion to a linear motion of the pusher connected to it. The samples to be counted are placed in lucite sample holders and stacked in order in a column. The pusher strips off the bottom sample holder during its forward motion. Upon its return, the stack of holders descends one position. On the next cycle the pusher strips off the second sample holder which in turn pushes the first one under the G.M. tube encased in a lead shield. On the third cycle the second holder is pushed under the counter and the first holder is pushed onto a moving platform at the base of a second stack. A second rod, actuated by the rotating arm as it completes a cycle, raises the platform with the sample so that the next sample may easily slide under. The moving platform raises each sample holder it receives until a catch grabs hold, and it then springs back into place as the rotating arm is disengaged from the second rod.

The sample changing mechanism completes its cycle in seven seconds. An automatic timer is incorporated to provide any predetermined length of count. A sample change cycle as described above will take place after each count. Three counting ranges of 0 - 1000, 0 - 2000 and 0 - 5000 counts are available. The recording is automatic although the start of the first count must be indicated manually on the recorder chart.

The unit will not turn itself off after having counted all the samples. This feature can be used to obtain a decay on the final sample or a background if the final sample holder contains no sample. The dummy sample holder is used at the end since it does not get pushed under the counter.

4. Automatic Decay Recorder: To provide a visual record of sample decay an Esterline-Angus recorder may be used in conjunction with a scaler. A Veeder-Root register is used with microswitches on the tens, hundreds, and thousands digits modified to be activated by the units, tens, and

hundreds digits. The output of the scaler is thus used to operate three pens of an Esterline-Angus (ten-pen) recorder. The three pens give pips for each register, each ten registers, and each hundred registers respectively.

5. Regulated Power Supply: To insure stable operation of the counting equipment it is advisable to have a regulated power supply to provide constant voltage. This is obtained by the insertion of sola transformers and filters in the main line as shown in Figure 7. An Esterline-Angus recording voltmeter records any changes in either the unregulated or regulated voltage as determined by the position of the selector switch. A variac has been included in each regulated circuit to adjust the load for any changes that may occur, since it is advisable to operate the sola transformer with proper load (75-100%, see company circulars for further details). A variable resistance with adequate current capacity can be used instead of the variacs for this purpose. If no frequent load changes are contemplated in setting up a counting room, this feature can be eliminated.

In addition, a line filter is placed in series with each scaling unit to prevent noise from this unit getting through to any other scaler or amplifier unit. The unregulated line is also available for miscellaneous use and for the timers, etc. in the counting room.

II. Counting Room Procedures

A. Background

Before using any counter its background should be determined. This is done by taking a 30-minute count with no sample present and computing the counts per minute registered by that counter due to the prevalent background. Background for each counter is recorded daily in a log book. It would be advisable to take a background count at random during the day since there are several naturally occurring factors which may affect the background counting level: e.g. change in temperature affecting the operating characteristics of the counter, the hysteresis effect in the counter after counting at a high rate. Normally this single random background count would be sufficient and could be applied to all samples counted during the day. However, since there are a number of common and frequent causes for changing background at the counting room which are appreciable in magnitude, it is usually necessary to make at least two such checks during the day.

For low level counting it is desirable to have available some unit which continually indicates the background in the room where counting is being done. A recording ratemeter is suitable for this purpose. This is advisable so that any change in background can be easily and quickly detected in order that counter backgrounds may be redetermined.

It has been found useful to check each counter periodically with a standard source to see if its response is consistent. This check would show up such defects as double pulsing, scaler defects, high voltage leaks,

and register defects. These defects may or may not be noticed during the routine background checks.

B. Voltage Plateaus

Before any counter is put into use a voltage plateau must be obtained and the proper operating point determined. Any source producing the desired type and intensity of radiation may be used. The high voltage is increased until counts begin to appear. This point is determined by the scaler sensitivity. Then short counts (two minutes) are taken at twenty-five volt intervals for about 250 volts past the point where counts first appeared or until definite signs of rapidly increasing counting rates appear, whichever is less. Never operate a tube at a voltage high enough to cause a continuous discharge. Many tubes will become permanently damaged if this caution is disregarded. If the voltage has been increased beyond the plateau, repeatability of points on the plateau will not be obtained due to the hysteresis effect which is present. This is due to the accumulation of charge on the inside of the counter window. This latter precaution does not apply to the flow counters; however, some hysteresis is noticed when the voltage is raised and then lowered. In all cases the counter should be rested for a while before increasing the H.V. again.

If counts per minute are plotted against voltage, a plateau about 150-200 volts in length will be observed if the counter is functioning properly. The operating point should be chosen about 75 volts above the beginning of the plateau.

Any new Geiger-Muller tube should be tested to determine the operating voltage and to see if it has a good plateau. Plateaus on all counters should be rechecked occasionally, or whenever there is some doubt concerning the characteristics of the tube.

C. Counting Efficiency

Counting efficiency is the ratio of recorded counts to the actual disintegrations occurring in the sample, or

$$\text{counting efficiency} = \frac{\text{observed c/m}}{\text{d/m of sample}} \quad (1)$$

Overall counting efficiency is a function of

1. Counter efficiency = $\frac{\text{no. of ionizing particles * counted}}{\text{no. of ionizing particles * entering counter}}$ (2)
2. Geometry, which is the solid angle subtended by the sample at the counter. This is dependent on the relative position and size of the sample and the counter.

*The term particle as used here includes photons.

3. Absorption in the sample, in the air between the sample and the counter if any, and the counter window.
4. Scattering from the backing material, the sample supports, shield and air between counter and source.

Before meaningful results can be obtained, the efficiency of the counter being used must be determined for the sample in question. This may be done by comparing the sample with a source of the same isotope mounted the same way as the sample. However, if a large number of routine samples are to be counted in which the isotopes present are frequently unknown, this method is not feasible. It is, therefore, desirable to use a standard and apply the necessary corrections to obtain the efficiency for the type of sample in question.

Plutonium discs are usually used for determining alpha efficiencies and radium D and E sources from the National Bureau of Standards for beta efficiencies.

To determine the counting efficiency of an alpha scintillation counter or a continuous flow proportional counter, a calibrated alpha emitting source of about 600 to 1200 counts per minute is used, sufficiently large so that good statistics are obtained in a short time. Such a source is counted for a period of about ten minutes. The observed counts per minute are recorded. This figure is then divided by the known disintegrations per minute of the source. It is recommended that this process be repeated using one or two other sources and the results averaged. If the range of results obtained is greater than the statistical limits indicate, there is something wrong and the situation should be reviewed. The counting efficiency is then obtained for a given sample position. No further corrections are needed since scattering is not appreciable and the efficiency is not dependent on sample size since both types of counters have a flat response over most of the sample area making the correction negligibly small.

To determine the beta efficiency of an end-window or flow counter, the radium D and E source is placed in the position for which the efficiency is desired and a standard aluminum absorption curve is obtained. Since the source emits both alpha and beta particles, a minimum of about 7 mg/cm² of aluminum must be used to stop the alpha particles. The counting rates are plotted against absorber thickness on semi-log paper. This plot is then extrapolated back to zero aluminum absorber thickness giving the counting rate at this point. Background is subtracted from this figure and the resultant is divided by the known disintegration rate of the source giving the efficiency for a radium D and E source in that position. Experience indicates that this procedure is susceptible to appreciable error for several reasons. The extrapolation, which is usually done by visually fitting a straight line to the points plotted on the semi-log paper, is very rough and subject to sizable error. A more accurate efficiency determination would require a more accurate technique of line fitting devoid of human bias. Therefore, it is recommended that sufficient points on the absorption curve be obtained to make it feasible to fit a least squares line to the points. At least 9 or 10 points are necessary for a good fit. Since this procedure

is somewhat involved, it should be done when initially determining the counter efficiency. Subsequent checks can then be made by counting the standard under one or two absorbers and if the points obtained fall within the 90% error figure about the least squares fit then the original efficiency figure can be used; if not, a new determination is in order. This method assumes a good set of absorbers.

In the past, the absorbers used have been found quite inaccurate. It is surmised that either the thickness is inaccurately determined or the composition of the aluminum used varies from absorber to absorber.

If these two sources of error are rectified, the efficiencies should prove to be a good deal more consistent. An example of this procedure with appropriate reference is given in the Appendix.

The efficiency of an end-window counter is greatest at a point directly under the center of the counter and decreases rapidly with increasing distance from the center. (Fig. 8). It is, therefore, necessary to correct for the difference between the size of the source and the size of the sample, as a counter will have greater efficiency for a small sample than for a large sample of the same specific activity. To obtain this correction factor, the following point source method is used.

A point source is placed in the counter on the shelf in question and counted directly under the center of the counter window or sensitive area. The source is then moved out a small distance from the center and counted again. This process is repeated, counting at small equal intervals from the center out to a distance equal to the radius of the sample. With the count at the center represented by one, the relative count is plotted on linear graph paper against the distance from the center. (See Figure 8).

The area of the sample used is arbitrarily divided into concentric rings and the area of each ring calculated. The mean distance of each ring from the center of the sample measured along a radial line is determined. The relative counts corresponding to these distances may then be obtained from the graph. The area of each ring is multiplied by the relative count corresponding to the mean distance of the ring from the center. These results are totalled and this total is divided by the area of the entire sample. This gives the correction factor for a sample of a specified area, assuming uniform distribution of the activity on the sample, relative to a point source.

These calculations are then repeated for the standard source giving the correction factor for the standard relative to a point source at the center.

The above correction factor for the sample when divided by the correction factor for the standard gives the conversion factor of the sample with respect to the standard source.

The following is an example using a standard radium D and E source to obtain the correction factor for a sample evaporated on a planchet of the usual size.

Correction Factor for Planchet Relative to a Point Source at the Center

<u>Zone</u>	<u>Area in mm²</u>	<u>Relative Count</u>	<u>Area x Relative Count</u>
a	3.14	.998	3.13
b	9.42	.996	9.38
c	15.70	.988	15.51
d	21.98	.981	21.56
e	28.26	.970	27.41
f	35.54	.960	33.16
g	40.82	.943	38.47
h	47.10	.925	43.57
i	53.38	.901	48.10
j	59.66	.889	53.04
k	65.94	.847	55.85
l	72.22	.808	58.35
m	78.50	.773	60.68
n	84.78	.735	62.31
o	91.06	.681	62.01
p	97.34	.623	60.64
q	103.62	.555	75.59
r	<u>109.90</u>	<u>.438</u>	<u>87.16</u>
	1017		816

$$\frac{816}{1017} = .80$$

Correction Factor for Standard Relative to a Point Source at the Center

<u>Zone</u>	<u>Area in mm²</u>	<u>Relative Count</u>	<u>Area x Relative Count</u>
a	3.14	.998	3.13
b	9.42	.996	9.38
c	15.70	.988	15.51
d	21.98	.981	21.56
e	28.26	.970	27.41
f	<u>35.54</u>	<u>.960</u>	<u>33.16</u>
	113		110

$$\frac{110}{113} = .97$$

$$\frac{80}{97} = .82$$

To obtain a further correction to the efficiency of a counting process, the effect of backscatter must be taken into consideration and a correction factor applied. Some radiation emitted from the sample in a direction away from the sensitive volume of the counter will be scattered into this volume by the backing upon which the sample rests. The magnitude of this effect increases with increasing particle energy and with increasing atomic number of the backing material. However, as the thickness of backing material is increased, the backscatter coefficient approaches a maximum value.

Some backscatter corrections for beta emitters of greater than 0.6 mev energy are as follows:^{3,18}

<u>Material</u>	<u>End Window GM Counter</u>	<u>Gas Flow Counter</u>
filter paper	1.10	-
aluminum	1.28	1.30
glass	1.22	
iron		1.46
copper	1.46	1.50
stainless steel	1.50	
silver	1.60	1.62
silver palladium	1.66	
gold		1.78
platinum	1.70	1.78
lead		1.80

Therefore, the reduction in efficiency of aluminum planchet compared with the radium D and E due to backscatter is the ratio $\frac{1.29}{1.66}$

Lead shields are usually lined with brass to eliminate the detection of alpha particles originating in the lead. The sample holders are mounted in lucite because lucite has a small scattering coefficient. This makes the effect of scattering from the support and shield walls negligible.

It is desirable to prepare samples for counting so that they are as thin as possible in order that corrections for self-absorption are negligible. Such correction factors can be determined experimentally if necessary.

In general it can be said that overall efficiency increases with particle energy. This relationship is not direct, but is a result of the energy dependence of the various factors previously discussed. At energies greater than one mev the variation is slight. However, at lower energies there is an appreciable effect which is primarily due to window and air absorption. Therefore, if an efficiency is determined for a particular particle energy it will not apply accurately for other energies. If the particle energy of the sample is known, a correction factor may be applied. Figure 9 shows the efficiencies as a function of beta energy.

Counting efficiency of a GM tube decreases rapidly with increasing distance of the sample from the counter. The following is an example of the efficiencies obtained for various shelves of a sample holder.

<u>Shelf</u>	<u>Distance from Window</u>	<u>Efficiency</u>
1	21.9 mm	12.1%
2	37.8	5.3
3	53.7	2.9
4	69.6	1.7
5	85.5	1.0

D. Taking a Count and Calculation of Results

In general, facilities are available for a sample to be exposed to the counter at various distances. It is usually desirable to use the arrangement which brings the sample closest to the sensitive volume of the counter to obtain maximum efficiency. However, if the sample has high activity it may be moved to a shelf or slot where efficiency is lower in order to minimize coincidence loss. (See section E below).

When the sample is placed in the counter the lights are cleared by means of the reset switch and the register is cleared. The automatic time or predetermined count switch is then set in the desired position.

When the count is complete, the total number of counts is determined from the combination of registers and lights that is shown. The total count is divided by the time of count in minutes, giving counts per minute. To compute the error for this count which will give 90% reliability, make use of the formula

$$\text{Error in cpm} = \frac{\pm 1.645 \sqrt{\text{total count}}}{\text{time interval of count in minutes}} \quad (1)$$

Graphs are available which eliminate the necessity of recalculating the error for each routine count. (Figure 10).

Background in counts per minute is subtracted from the gross counts per minute obtained above. This gives the net counts per minute.

The net error is computed by taking the square root of the sum of the squares of the two known errors, i.e.,

$$E_c = \sqrt{E_o^2 + E_b^2} \quad (2)$$

where E_c = error for net counting rate

E_o = error for observed c/m

E_b = error for background c/m

To determine disintegrations per minute the corrected counts per minute is divided by the factor for the overall counter efficiency.

For a sample of definite volume it may be desirable to find the results in terms of curies per unit volume. A curie is defined to be 3.7×10^{10} disintegrations per second. Therefore, to determine curies per unit volume, divide the disintegrations per minute by $3.7 \times 10^{10} \times 60 \times \text{volume}$. For example:

Assume a 500-ml sample shows 14 registers and one light on a scale of 64 scaler after counting for 30 minutes. The counter efficiency is 12%. Background is 21.0 ± 1.4 c/m.

$$\text{Total count} = 14 \times 64 + 1 = 897 \text{ counts}$$

$$\text{Gross counting rate} = \frac{897}{30} = 29.9 \pm 1.6 \text{ c/m}$$

$$\text{Background} = 21.0 \pm 1.4 \text{ c/m}$$

$$\text{Net counting rate} = 8.9 \pm 2.1$$

$$d/m = \frac{8.9}{0.12} \pm \frac{2.1}{0.12} = 74 \pm 18$$

$$c/cc = \frac{74}{3.7 \times 10^{10} \times 60 \times 500} \pm \frac{18}{3.7 \times 10^{10} \times 60 \times 500}$$

$$c/cc = 6.7 \times 10^{-14} \pm 1.6 \times 10^{-14}$$

The results of air samples may be calculated in terms of microcuries per liter or curies per cc. Since an air sample normally has a high background count due to radon and thoron and their daughters, it is necessary to allow these products to decay before a true count of activity due to a long-lived product may be taken. The radon daughters may be considered as completely decayed six hours after the end of sampling. Thoron daughters will not decay for several days. However, by taking counts roughly 6 and 24 hours after sampling, the count due to long-lived products may be determined from the equation

$$c = \frac{c_2 - c_1 e^{-\lambda \Delta t}}{1 - e^{-\lambda \Delta t}} \quad (3)$$

where c_1 is the count taken about six hours after sampling.

c_2 is the count taken about 24 hours after sampling.

$\lambda = 0.0655$ ($\lambda = .693/\text{half life}$, calculated for thorium "B" with a half life of 10.6 hours.)

Δt is the time in hours elapsed between 6- and 24-hour counts.

c is the count due to long-lived products.

c_1 , c_2 and c are all in counts per minute.

The activity of air samples is commonly expressed in microcuries per liter. Conversion is performed as follows:

$$\text{microcuries/liter} = \frac{c_{11}}{c \times g \times 3.7 \times 10^4 \times 60 \times v \times 28.3}$$

where c = collection efficiency of the filter system

g = efficiency of the counter

v = volume of air in cubic feet

28.3 number of liters per cubic foot.

In the above calculations the definition of the curie was presumed to be that amount of radioactive material which disintegrates at the rate of 3.7×10^{10} atoms per second. The above formulæ are based on the further assumption that the decay schemes are simple beta decays and that there is

no K capture or gamma-electron conversion and that the counter efficiency for gamma rays is zero. If these assumptions are known to be invalid for any particular sample, appropriate corrections are in order. (See ref. 21).

E. Dead Time

After an ionizing event has occurred in the counter there is a time during which it is insensitive to additional ionizing events. This is called the dead time of the counter. Any count arriving during this time is lost. This is referred to as coincidence loss. At high counting rates this coincidence loss is appreciable and corrections must be made if good accuracy is to be obtained. The common methods for determining the dead time of a counter are as follows:

1) If a pulse arriving within a time "T" following the first pulse does not extend the dead time the following analysis is applicable:

let n' = total number of counts recorded during an interval t .

n = number of particles actually passing through sensitive volume of the counter.

T = dead time of counter.

Then $n - n'$ = number of counts lost.

$n'T$ = total insensitive time of the counter.

The average number of input counts falling in this interval and thus are lost is $(\frac{n}{t})n'T$, where $\frac{n}{t} = R$, the input pulse rate.

Therefore, $n - n' = (\frac{n}{t})n'T$

dividing each side by t we have

$$\frac{n}{t} - \frac{n'}{t} = \frac{n}{t} \cdot \frac{n'}{t} \cdot T$$

or $R - R' = R' \cdot R \cdot T$

solving for R

we have $R = \frac{R'}{1 - R'T}$ (1)

2) If the pulse arriving within a time "T" following the previous pulse does extend the dead time by "T", the following analysis applies: (ref. 9 page 209).

A pulse can get through the detecting arrangement only when two input pulses are separated by an interval $\geq T$.

Therefore: $n' = nP_0$ or $R' = RP_0$ where

P_0 is the probability that a pulse will not occur in the interval "T". The mean number of pulses that will occur in the interval "T" is RT . Now using the "Poisson Distribution" formula

$$P_n(\bar{n})d\bar{n} = \frac{\bar{n}^n e^{-\bar{n}}}{n!} d\bar{n} \quad (2)$$

we have for $\bar{n} = RT$ and $n = 0$

$$P_0 = e^{-RT} \text{ therefore } R' = Re^{-RT} \text{ from above,}$$

$$\text{or } R = R'e^{RT} \quad (3)$$

As $RT \rightarrow 0$ the two methods approach each other. As mentioned in reference 9, actual detectors are usually intermediate between these two classes in behavior. In the following analysis, method "1" will be employed arbitrarily for ease of calculation.

Use two point sources, count each alone, and then both together.

From method 1 above, (here N_1 , N_2 , n_1 , n_2 and n_{12} are counting rates in counts per second.)

$$N_1 = \frac{n_1}{1 - n_1 T} \text{ and } N_2 = \frac{n_2}{1 - n_2 T}$$

$$N_1 + N_2 = \frac{n_{12}}{1 - n_{12} T}$$

Solving for T and neglecting second order terms in T

$$T = \frac{n_1 + n_2 - n_{12}}{2n_1 n_2} \quad (4)$$

The error in T is calculated by the following formula (see formula "f" in section G below).

$$E_t = \frac{1}{2n_1 n_2} \sqrt{\left(\frac{n_{12} - n_2}{n_1}\right)^2 E_1^2 + \left(\frac{n_{12} - n_1}{n_2}\right)^2 E_2^2 + E_{12}^2} \quad (5)$$

Once the dead time of the counter is known the number of real counts may be computed from (1) above by using relation

$$R = \frac{R'}{1 - R'T}$$

Thus, using a counter with a dead time of 6×10^{-4} sec., a counting rate of 10,000 counts per minute would have an error of 10% due to coincidence loss alone.

As an example of a dead time determination

$$\begin{aligned} n_1 &= 1000 \pm 25 \\ n_2 &= 2000 \pm 35 \\ n_{12} &= 2500 \pm 40 \\ T &= \frac{1000 + 2000 - 2500}{2 \times 1000 \times 2000} \\ &= \frac{500}{4 \times 10^6} = 1.25 \times 10^{-4} \text{ sec} \end{aligned}$$

$$\begin{aligned} E_t &= \frac{1}{4 \times 10^6} \sqrt{\left(\frac{1}{2}\right)^2 \cdot 625 + \left(\frac{3}{4}\right)^2 \cdot 1225 + 1600} \\ &= .124 \times 10^{-4} \text{ sec} \end{aligned}$$

F. Calculation of Statistical Errors in Counting^{10,11}

The nature of radioactive decay results in a certain amount of uncertainty in the results of any attempt to measure the rate at which the radioactive material is disintegrating. Therefore, whenever a count is made, it is useful to accompany the results with a figure of reliability determined a Priori as appropriate for the measurement being made. The statistical reliability figure customarily employed in the Health Physics Counting Rooms is one (based on the normal or Gaussian distribution) which implies that the chances are 9 to 1 that the true disintegration rate does not differ from that obtained, by more than the limits expressed. This is called the 90% error figure, or statistical reliability figure. The probable error (50%) and the Standard derivation (68%) are also used frequently. Although the Radioactive decay follows a Poisson Distribution, the Gaussian distribution approximation is adequate for all but extremely low counting rates.

As an example: if we have the results stated as follows

$$\text{"C" counts} \pm E$$

This means that the true counting rate lies somewhere between (C-E) and (C+E) with a reliability of 90%. Or, if a sufficiently large number of independent counts were taken under identical conditions, 90% of these would fall within the limits given.

In dealing with two or more quantities and their associated errors, the following relations are applicable. Let

$$\begin{aligned} r_1 &= \text{error in count } z_1 \\ r_2 &= \text{error in count } z_2 \\ r_n &= \text{error in count } z_n \end{aligned}$$

where $z_1, z_2, \dots, z_n$ are independent observed quantities. Then the

errors for various combinations of these are as follows:

a. sum and/or difference of n independent observed quantities:

$$(z_1 \pm r_1) \pm (z_2 \pm r_2) \pm \dots \pm (z_n \pm r_n) = (z_1 \pm z_2 \pm z_3 \pm \dots \pm z_n) \pm \sqrt{r_1^2 + r_2^2 + \dots + r_n^2}$$

b. product of two counts:

$$(z_1 \pm r_1) (z_2 \pm r_2) = z_1 z_2 \pm \sqrt{r_1^2 z_2^2 + r_2^2 z_1^2}$$

c. if the z 's have constant multipliers:

$$A(z_1 \pm r_1) \pm B(z_2 \pm r_2) + \dots = Az_1 \pm Bz_2 \pm Cz_3 \pm \dots \pm \sqrt{A^2 r_1^2 + B^2 r_2^2 + \dots}$$

d. quotient of two counts:

$$\frac{z_1 \pm r_1}{z_2 \pm r_2} = \frac{z_1}{z_2} \pm \frac{z_1}{z_2} \frac{r_1^2}{z_1^2} + \frac{r_2^2}{z_2^2}$$

e. let Z be any function of the independent observed quantities:

$$Z = f(z_1, z_2, z_3, \dots)$$

$$Z \pm R = f[(z_1 \pm r_1), (z_2 \pm r_2), (z_3 \pm r_3), \dots]$$

To find R we have by Taylor's expansion neglecting terms of second and higher powers of r .

$$R = \sqrt{\left(\frac{dZ}{dz_1}\right)^2 r_1^2 + \left(\frac{dZ}{dz_2}\right)^2 r_2^2 + \left(\frac{dZ}{dz_3}\right)^2 r_3^2 + \dots}$$

As an example of formula e, let us derive d

$$Z \pm R = \frac{z_1 \pm r_1}{z_2 \pm r_2}, \quad Z = \frac{z_1}{z_2} \quad \left(\frac{dZ}{dz_1}\right)^2 = \frac{1}{z_2^2}; \quad \left(\frac{dZ}{dz_2}\right)^2 = \frac{z_1^2}{z_2^4}$$

$$\begin{aligned} \therefore R^2 &= \frac{r_1^2}{z_2^2} + \frac{z_1^2 r_2^2}{z_2^4} \\ &= \frac{z_1^2}{z_2^2} \left(\frac{r_1^2}{z_1^2} + \frac{r_2^2}{z_2^2} \right) \end{aligned}$$

or

$$Z \pm R = \frac{z_1}{z_2} \pm \frac{z_1}{z_2} \sqrt{\frac{r_1^2}{z_1^2} + \frac{r_2^2}{z_2^2}}$$

G. Minimum Detectable Activity

It is important to know the limitations of counting instruments in detecting activity. A factor which controls this limit is the total background of the instrument.

If a count of a sample plus background is taken and its associated error is determined as described above, then the total counting rate is

$$(S + B) \pm k \sqrt{S+B}$$

where S = total count for sample

B = background count for same period of time

k = constant which depends on the degree of reliability desired (k = 1.645 for 90% reliability).

The background can be expressed as

$$B \pm k \sqrt{B}.$$

Subtracting background from the total count we obtain

$$S \pm k \sqrt{S + 2B}$$

The minimum detectable activity may be defined by the relation

$$S_{\min \text{ det}} = k \sqrt{S_{\min \text{ det}} + 2B} \quad (1)$$

This relationship is based upon the statistical reliability figure employed in all the counting calculations. This means that for any activity to be considered as significantly above background it must be equal to or greater than the error as derived above. Therefore, the value of this error is assumed as the minimum detectable activity provided no other disturbing effects are present.

For convenience let " $S_{\min \text{ det}}$ " be labeled " S_1 ".

Solving the above expression for S_1 we obtain

$$\begin{aligned}
 S_1^2 &= k^2 S_1 + 2Bk^2 \\
 S_1^2 - k^2 S_1 - 2Bk^2 &= 0 \\
 S_1 &= \frac{k^2 \pm \sqrt{k^4 + 8Bk^2}}{2} \\
 &= \frac{k^2}{2} \pm \frac{k}{2} \sqrt{k^2 + 8B} \\
 S_1 &= \frac{k}{2} \left[k \pm \sqrt{k^2 + 8B} \right] \quad (2)
 \end{aligned}$$

Therefore, the minimum detectable activity is a function of "k" and the background "B". It should be noted that only the + sign has any meaning.

This derivation applies only when the total counts are sufficiently large so that the normal distribution is a good approximation to the Poisson distribution¹⁰.

As an example: the background of one of the β counters is about 18 ± 1.3 c/m (30-min count). Therefore, assuming the 90% statistical reliability figure, the minimum detectable activity is

$$\begin{aligned}
 S &= \frac{1.645}{2} \left[1.645 + \sqrt{(1.645)^2 + 8 \times 540} \right] \\
 S &= 55.4 \text{ counts in 30 minutes or} \\
 S &= 1.8 \text{ c/m as indicated in reference (5).}
 \end{aligned}$$

It is important to realize that the value obtained for "S" is the activity counted for the same length of time as that used for "B" when substituting in the formula. If, for example, we used "B" = 18 c/m in the above, we obtain $S = 11.3$ counts for a one-minute count. This illustrates again the well known fact that the longer count will yield more information.

H. Half Life Determinations

The frequency of taking counts for a half life determination depends on the rate of decay. The automatic sample changer described above is especially convenient if the half life is of fairly short duration. On the other hand, if the half life is several days or greater in length, a count may be taken once or twice a day and the corrected counts per minute determined.

Radioactive decay takes place according to the equation

$$N = N_0 e^{-\lambda t} \quad (1)$$

where N_0 = original number of atoms present
 N = number of atoms present at time t
 λ = decay constant
 t = time of decay

The half life $T_{1/2}$, is that value of t for which $N/N_0 = 1/2$.

From the above equation it can be seen that

$$\log N = \log N_0 - \lambda t \quad (2)$$

Thus if $\log N$ is plotted against t , a straight line having slope equal to $-\lambda$ will result.

This is done by plotting counting rate against time on semi-log paper. To determine $T_{1/2}$, choose any two convenient values of the counting rate such that the second is equal to one-half of the first. The difference in times between which these two values occur gives the half life of the material in question.

At times the curve obtained will not be a straight line, but will have two or more definite parts, each with a different slope, as shown below.

This indicates that more than one isotope is present. The first portion of the curve is characteristic of the mixture of isotopes; the second part is determined by one isotope only. The slope of the second part of the line may be found directly, but this must then be extrapolated back to zero time as shown by the dotted line. This is subtracted from the first part of the curve and the slope of the resulting line is used to find the half life of the shorter lived isotopes.

I. Determination of Beta Particle Energies⁷

Beta particles emitted by Nuclei in general have a continuous energy distribution. Exceptions to this, as a rule, are caused by the emission of conversion electrons from among the orbital electrons by photons ejected from excited nuclei. These electrons possess discrete kinetic energies.^{7,13}

Because of the nature of beta spectra, absorption curves can be used as a means for determining maximum beta energies.^{16,17} Fermi, in 1934, proposed a theory of beta decay which predicts the shape of these continuous spectra, and, if, the absorption curves are calculated from this theory, fairly good agreement is obtained in most cases. The straightness of the curve is a function of the degree of forbiddenness of the transition. It is also dependent on the maximum energy of the beta radiation. Greater maximum energy will cause the spectrum to be shifted toward the higher energy region and the absorption curve will be more concave to the coordinates. The greater the degree of forbiddenness, the more the spectrum will be displaced toward the lower energies and the absorption curve will be more nearly exponential.¹⁴

The shape of a beta absorption curve is also dependent on the absorber material, the curves becoming more concave with increasing atomic number of the absorber material. The use of aluminum absorbers approximates a linear relationship due to the balancing of the effects of scattering and absorption. Although the shapes of the curves differ, the apparent range is independent of the absorber material used. The choice of aluminum is recommended for use in obtaining absorption curves for the purpose of determining the range and maximum energy of beta particles.

For a description of the absorption curves for conversion electrons, see reference 7.

To obtain an absorption curve the sample is counted in a position that will give a sufficiently large counting rate. A position giving about 10,000 counts per minute is desirable since it is best to carry an absorption curve through four orders of magnitude to obtain greatest accuracy. Aluminum absorbers of increasing thickness are placed between the sample and the counter, as near the counter as possible to avoid the scattering of radiation into the counter by the absorber. A count is taken with each absorber in place and the net counts per minute determined. This is plotted against total absorber thickness (including air gap, counter window, and source covering) in mg/cm^2 on semi-log graph paper. If gamma radiation is present the line will become nearly horizontal at some point on the abscissa before background is reached.

There are two commonly used techniques for determining the maximum beta energy. The more accurate is the Feather comparison method described in references 7 and 13. The second is the visual method which is sufficiently accurate in most cases to yield adequate information for identification purposes. Here the background is not subtracted from the resultant counts. The visual range is the thickness of absorber through which one can no longer observe beta activity above the background, or gamma activity. It is necessary that long counts be taken as the activity approaches this level. When the range has been found the energy may be determined from a range-energy curve (fig. 11) or from Feather's laws which give the following empirical relations:

$$E = 1.85 R + 0.245 \text{ for } R > 0.3 \text{ gm/cm}^2 \quad (1)$$

$$E = 1.92 R^{(0.725)} \text{ for } 0.03 \text{ gm/cm}^2 < R < 0.3 \text{ gm/cm}^2 \quad (2)$$

where

R = range in gm/cm^2

E = energy in mev

For complex spectra the line is broken up into two or more straight sections which may in simple cases be analyzed by subtraction of the line due to the isotope having the greater maximum beta energy.

The disadvantage of this method is that, although quite simple, it is applicable only in cases where gamma activity has a low intensity (i.e., a counting rate less than $\sim 0.5\%$ of the beta activity). Where the gamma activity is greater, as is common, the range obtained is usually considerably less than the actual range; and the higher the gamma background, the greater the resultant error. In such cases the Feather Comparison method is preferable.

J. Determination of Gamma and X-Ray Energies⁷

The absorption of photons by matter is exponential and proceeds according to the equation:

$$I = I_0 e^{-\mu x} \quad (1)$$

where I_0 = intensity of radiation incident on the absorber.
 I = intensity of radiation passing through the absorber.
 μ = linear absorption coefficient.
 x = absorber thickness.

Then

$$\log I = \log I_0 - \mu x \quad (2)$$

Gamma energies may be obtained by a procedure similar to that described above for beta energies. However, a high atomic number element is used to provide adequate absorption for the more penetrating gamma photons. Lead is usually used for the high energy photons, aluminum for the soft gammas and x-rays. From the curve, the absorption coefficient can be estimated, and this value can then be related to the energy by referring to tables of energy-absorption coefficients or appropriate curves relating the two.⁷

It is frequently convenient to determine gamma energies from half-value layers in lead. This is done by plotting the lead absorption curve and noting the thickness of lead necessary to reduce the intensity by a factor of two.

Some absorption coefficients and half-value layers are given below:¹⁵

Linear Absorption Coefficients in Lead for Gamma Radiation

<u>E</u>	<u>μ</u>	<u>E</u>	<u>μ</u>
0.5 Mev	4.36 per inch	1.6 Mev	1.39 per inch
0.6	3.62	1.7	1.34
0.7	3.02	1.8	1.29
0.8	2.54	1.9	1.24
0.9	2.20	2.0	1.21
1.0	1.98	2.2	1.16
1.1	1.82	2.4	1.13
1.2	1.71	2.6	1.12
1.3	1.61	2.8	1.11
1.4	1.52	3.0	1.11
1.5	1.45		

Half-value Layers in Lead for Gamma Radiation

<u>E</u>	<u>$X_{1/2}$</u>	<u>E</u>	<u>$X_{1/2}$</u>
0.5 Mev	.159 inch	1.6 Mev	.499 inch
0.6	.191	1.7	.517
0.7	.230	1.8	.537
0.8	.273	1.9	.559
0.9	.315	2.0	.573
1.0	.350	2.2	.597
1.1	.381	2.4	.613
1.2	.405	2.6	.619
1.3	.430	2.8	.625
1.4	.456	3.0	.625
1.5	.478		

III. Laboratory Procedures for Sample Preparation

The choice of methods to be used in the preparation of a sample for counting depends on the nature of the sample and the isotopes which it is expected to contain. Below are given the methods of preparation of the most common types of samples handled in this laboratory. Various combinations of these may be used.

Liquid Sewage

1. Place 500 ml. of liquid sewage in a separatory funnel.
2. 100 ml. of this sewage is placed in a 200 ml. beaker.
3. The beaker is heated in a heating mantle. The temperature of the liquid is controlled with a variac.
4. As the sewage evaporates from the beaker more is added from the separatory funnel until the total 500 ml. has been added to the beaker.
5. The volume is boiled down to approximately 10 ml.

6. The last 10 ml. are transferred from the beaker to an aluminum planchet with an eyedropper and evaporated to dryness on an aluminum planchet under infra-red lamps.
7. The separatory funnel and eyedropper may be coated with drifilm to prevent sticking to the walls.

Rain

1. Using Whatman No. 42 paper, filter with suction all of the rain that has been collected, noting the total volume.
2. Repeat the filter process using Millipore hydrosol molecular filter paper.
3. Place the filter papers with the residue in a silica crucible in the large oven in the hood.
4. Bring oven to 900°C. Let cool and transfer ash to aluminum planchet*.
5. Boil down 1000 ml. of the filtrate in a covered beaker with 30 ml. concentrated HNO_3 .
6. Evaporate to dryness on an aluminum planchet under an infra-red lamp.

Settled Atmospheric Dust

A. Collection

1. Obtain sample to be processed by washing collector with 1 gal. distilled water and catch wash in pail.
2. Scrub collector and pail with water and soap. Discard this.
3. Rinse collector and pail with tap water. Discard rinse water.

B. Preparation

Follow the procedure as given for rain.

Iodine Extraction

A. Place 500 ml. of sample in a large separatory funnel.

1. Add 1 ml. 2M Na_2CO_3 (sodium carbonate).
2. Add 2 ml. KI (potassium iodide).
3. Oxidize with 1 ml. Chlorox.
4. Acidify by adding slowly 3 ml. concentrated HNO_3 .
5. Reduce with 3 ml. of hydroxylamine hydrochloride ($\text{NH}_2\text{OH HCl}$).
6. Extract the iodine with four 25 ml. portions of carbon tetrachloride (C Cl_4) or until no further color is noticed in the C Cl_4 layer. Combine the C Cl_4 extracts.
7. Put stopper in funnel and shake well until rose color appears in each case.
8. Remove stopper and discard the water layer.

B. Transfer C Cl_4 layer to smaller separatory funnel.

1. Add 10 ml. distilled water.
2. Add a few drops of sodium bisulfite (NaHSO_3).

*Cover ash with a thin coat of highly thinned out general cement.

3. Shake until colorless.
4. Discard the $C Cl_4$ layer with beaker.

C. Return solution to small separatory funnel.

1. Add 1 ml. 6N HNO_3 .
2. Add a few drops of sodium nitrite ($NaHO_2$)
3. Extract the iodine with four 10 ml. portions of $C Cl_4$ or until no further color is noted in the $C Cl_4$ layer.
4. Combine the $C Cl_4$ extracts and discard the water layer.

D. Repeat step B.

E. With solution in small funnel.

1. Add 1 ml. 6N HNO_3 .
2. Transfer solution to small beaker and heat nearly to boiling.
3. With pipette add 2 ml. of 0.1N silver nitrate ($AgNO_3$) dropwise while stirring.
4. Boil gently and stir briskly for a few seconds.

F. Filter with suction on a small funnel and wash the precipitate with alcohol.

G. Transfer the precipitate to an aluminum planchet.

Phosphorus Extraction

1. Take 500 cc sample in 1000 ml. beaker with glass boiling beads.
2. Acidify with 5 cc HNO_3 to prevent too rigorous boiling.
3. Add 10 mg disodium phosphate (Na_2HPO_4) as the carrier.
4. Evaporate to small volume using jacket heater.
5. Transfer evaporated solution into 250 ml. beaker and estimate volume.
6. Add concentrated HNO_3 in an amount equal to $1/8$ of the volume of the evaporated solution. This is done to make the solution a 2 to 3 normal acid solution to get the correct reaction and precipitate.
7. Add NH_4NO_3 in an amount equal to 5% of the total volume.
8. Add 20 cc molybdic acid reagent, prepared as follows:
 - a. Dissolve 100 gm ammonium molybdate in 400 ml. of water. Add 80 ml. of 15 molar NH_4OH filter if cloudy.
 - b. Add 400 ml. of 16 molar HNO_3 to 600 ml. of water. Add one part of No. 1 to two parts of No. 2 with rapid stirring.
9. Heat solution until warm. Do not boil.
10. Let stand overnight.
11. Filter with suction.
12. Wash with 5% NH_4NO_3 solution. Some precipitate will still remain.
13. Wash with 5% NH_4NO_3 and 1% aerosol solution. Precipitate should mat down.
14. Wash with alcohol.

Surface and Ground Water

1. Filter the total volume with suction twice, as described for rain.
2. Ash the filter paper and place on planchet.
3. Boil down 1000 ml. sample without adding acid and 1000 ml. sample with 30 ml. concentrated HNO_3 .
4. Transfer to aluminum planchet and evaporate to dryness under infra-red lamp.

Miscellaneous Liquid Samples

1. Take two 500 ml. samples.
2. Add 15 ml. concentrated HNO_3 to one of the samples.
3. Boil both samples in covered beakers until about 5 ml. remains in each.
4. Evaporate to dryness on aluminum planchets under infra-red lamps.

Vegetation

Method A

1. Cut the vegetation into small pieces.
2. Dry in an evaporation dish under an infra-red lamp.
3. Pulverize the dried vegetation in the grinder until it is a fine powder.
4. Weigh out 0.50 gm on an aluminum planchet.

Method B

1. Digest a known weight of the vegetation, e.g. 1 gm in a solution of dilute HNO_3 .
2. Add concentrated HNO_3 to hasten digestion, if necessary.
3. Evaporate onto an aluminum planchet.

Soil

Weight out a known quantity as desired and place on planchet.

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1. Absorption Data for Counter Efficiency Determination.

As described in the text above, the standard is placed in the geometry desired with respect to the counter and a series of counts are taken using a number of aluminum absorbers of increasing thickness. Table I is a summary of the data.

Table I

Absorption Data for Counter Efficiency Determination

S. R. No.			Voltage	1425		
Counter No.	BGM-4		Bkgd.	20.5 ± 1.4 c/m		
Shelf No.	No. 3		Absorber	Set No. 406		
Date	5/11/54		By	M.M.W.		
mg/cm ²	Reg.	Lgts.	Total Count	L.C. Min.	c/m	net c/m
7.13	66	18	4242	2 min. ↓	2121.0	2101.5
10.6	61	31	3935		1967.5	1947.0
14.7	57	39	3687		1843.5	1823.0
19.4	56	40	3624		1812.0	1791.5
28.6	47	41	3049		1524.5	1504.0
45.9	35	10	2250		1125.0	1104.5
69.8	23	46	1518		759.0	738.5
101.0	14	20	916		458.0	437.5
149.0	6	46	430		215.0	194.5
165.0	5	22	342		171.0	150.5

Used Standard (Ra D and E) No. 2474 with 190.6^d/s.

2. Fitting Least Squares Curve to the Data.

The next step is to fit a least squares curve to the data. Now we have shown in the text above that a good approximation to the absorption data is the mathematical relation as follows:

$$R = R_0 e^{\lambda' t} \quad (1)$$

where t is thickness of absorber.

R is the counting rate with absorber of thickness " t ".

R_0 is the counting rate with an absorber of zero thickness.

λ' is a constant (always negative) indicating the rate of exponential decrease of the counting rate.

λ as employed in the following analysis includes the factor $\log_{10} e$ that is $\lambda = \lambda' \log_{10} e$.

To determine the parameters of this equation by the least squares method, the following equations must be solved.¹⁹

$$\left. \begin{aligned} \Sigma(\log R) &= n \log R_0 + \lambda \Sigma(t) \\ \Sigma(t \log R) &= \log R_0 \Sigma(t) + \lambda \Sigma(t^2) \end{aligned} \right\} \quad (2)$$

where n = the number of observations made, in this case $n = 10$.

Solving these equations for λ and $\log R_0$ we obtain the following expressions:

$$\lambda = \frac{\Sigma(t) \cdot \Sigma(\log R) - n \cdot \Sigma(t \log R)}{[\Sigma(t)]^2 - n \cdot \Sigma(t^2)} \quad (3)$$

$$\log R_0 = \frac{\Sigma(t^2) \cdot \Sigma(\log R) - \Sigma(t) \cdot \Sigma(t \log R)}{n \cdot \Sigma(t^2) - [\Sigma(t)]^2} \quad (4)$$

To obtain the standard error of estimate of $\log R$ the following relation is used:

$$S_{\log R}^2 = \frac{\Sigma[(\log R)^2] - \log R_0 \cdot \Sigma(\log R) - \lambda \Sigma(t \log R)}{n} \quad (5)$$

Table II presents the necessary tabulated data and calculations to obtain the above results.

Table II

Work Sheet for the Determination of the Least Squares Fit
to the Given Data and the Standard Error of Estimate

t	R	Log R	t ²	t · log R	(Log R) ²
7.13	2101.5	3.32253	50.8	23.68964	11.03921
10.6	1947.0	3.28937	112.4	34.86732	10.81995
14.7	1823.0	3.26079	216.1	47.93361	10.63275
19.4	1791.5	3.25322	376.4	63.11247	10.58344
28.6	1504.0	3.17725	818.0	90.86935	10.09492
45.9	1104.5	3.04317	2106.8	139.68150	9.26088
69.8	738.5	2.86835	4872.0	200.21083	8.22743
101.0	437.5	2.64098	10,201.0	266.73898	6.97477
149.0	194.5	2.28892	22,201.0	341.04908	5.23915
165.0	150.5	2.17754	27,225.0	359.29410	4.74168
sum	611.1	11,792.5	29,322.12	68,179.5	1567.44688
					87.61418

(Table II continued on next page)

$$\lambda = \frac{(611.1)(29.32212) - 10(1567.44688)}{(611.1)^2 - 10(68179.5)}$$

$$= \frac{17,918.7475 - 15,674.4688}{373,443 - 681,795} = \frac{2,244.2787}{-308,352}$$

$$\lambda = \underline{\underline{-.00728}}$$

$$\log R_o = \frac{(68179.5)(29.32212) - (611.1)(1567.44688)}{10(68179.5) - (611.1)^2}$$

$$= \frac{1,999,167.48054 - 957,866.78837}{308.352} = \frac{1041,300.69217}{308.352}$$

$$\underline{\underline{\log R_o = 3.37699}}$$

Therefore, $R_o = 2382.3$

$$E = \frac{2382.3}{190.6 \times 60} = \frac{2382.3}{11436} = \underline{\underline{20.8\%}}$$

$$S^2_{\log R} = \frac{87.61418 - 3.37699 \cdot 29.32212 + .00728 \cdot 1567.44688}{10}$$

$$= \frac{87.61418 - 99.0205060188* + 11.4110132864*}{10} = \frac{.0046872676*}{10}$$

$$= .00046872676$$

$$S_{\log R} = .02165$$

*Carrying these numbers to ten significant places is not quite legitimate. However, it is convenient since the square root is desirable to five places.

The results obtained in Table II are employed as follows:

First, the counter efficiency for the RaD and E is determined.

$$E = \frac{R_o}{\text{Standard's disintegration rate}} = \frac{2382.3}{190.6 \times 60} \quad (6)$$

$$= 20.8\%$$

Secondly, using the standard error of estimate of $\log R$, reliability limits can be set up. As mentioned in the text a 90% reliability limit is generally employed. Now the equation of average relationship is

$$\log R = \log R_o + \lambda t \quad (7)$$

in this example

$$\log R = 3.37699 - .00728 t \quad (8)$$

choosing one or two convenient values of t , we can set up reliability limits for the value of $\log R$ or R which can be used in making quick periodic checks of the efficiency figure calculated above. As long as the counting rate R remains within the limit specified the same efficiency figure can be used. If the value of R obtained is outside this limit, a new efficiency should be determined using the above procedure.

$$\begin{aligned} \text{Let } t_1 &= 14.7 \text{ mg/cm}^2 \\ t_2 &= 69.8 \text{ mg/cm}^2 \end{aligned}$$

From equation (8) above we have

$$\log R_1 = 3.37699 - (.00728)(14.7) = 3.26997$$

$$\log R_1 \pm 1.645 S_{\log R} = 3.26997 \pm 1.645 (.02165) = 3.26997 \pm .03561$$

$$\text{upper value of } R_1 = \text{anti log } 3.30558, \text{ or } R_1 \text{ max} = 2021.0$$

$$\text{lower value of } R_1 = \text{anti log } 3.23436, \quad R_1 \text{ min} = 1715.4$$

$$\log R_2 = 3.37699 - (.00728)(69.8) = 2.86885$$

$$\log R_2 \pm 1.645 S_{\log R} = 2.86885 \pm 1.645 (.02165) = 2.86885 \pm .03561$$

$$\text{upper value of } R_2 = \text{anti log } 2.90446, \text{ or } R_2 \text{ max} = 802.5$$

$$\text{lower value of } R_2 = \text{anti log } 2.83324, \text{ or } R_2 \text{ min} = 681.2$$

We now have a measure of the variation which can reasonably be expected in the counting rates obtained using the absorbers in question. This procedure yields an impersonal and mathematically consistent procedure for accepting or rejecting a previous efficiency figure. The counting rates obtained in these checks must be corrected for decay back to the time the above limits were determined in this case 5/11/54.

I. Introduction

A general lack of consistency among the three gas flow proportional counters in use in the counting room has been of some concern for some time. At first it was felt that perhaps the counters were subject to small changes in their efficiencies as a function of time which affected their response to a radioactive sample and caused this apparent lack of consistency. However, the procedures detailed in section II-c and Appendix I. resulted in consistent efficiencies which checked out during frequent efficiency checks as described above. Nevertheless, it was still not possible to use the three counters interchangeably which hampered the routine operations of the counting room, especially in such things as decay studies.

Another item of concern was the unusually low beta efficiencies obtained for these counters. The values obtained, using the methods described in the text, are all in the range of 40 to 50%. This is appreciably lower than the theoretically expected values. The counters under consideration have essentially 2π geometry. The backing material is aluminum which has a backscatter coefficient of about 1.3. Therefore the theoretical efficiency is about 65%.

These considerations occasioned the initiation of a rather thorough study of the response characteristics and efficiency of these counters. The following discussion and results summarizes the findings of this study. Miss S.E. Lax of the Area Survey Group completed this analysis under the supervision of the author and made some valuable and pertinent suggestions during the course of this study.

II. Study of Efficiency as a Function of Energy

The composition of the samples encountered in the routine analyses performed in the counting room is generally unknown. Therefore, the beta spectrum emitted by these samples is indeterminate. However, from previous studies (3), counter efficiencies have been shown to increase with beta energy until a plateau is reached at about 0.6 Mev. Above this value the efficiency is virtually independent of the energy. The study referred to above was done for geiger counters. However, since it is the dependence of the backscatter coefficient on beta energy which causes the efficiency to be a function of energy, the results for flow-counters may be presumed to be similar. This was confirmed for flow counters in a later study.⁽²²⁾

A survey of the more likely radioactive products in these routine samples reveal that most of them fall in the saturated region.

Procedure

The following isotopes were used to determine the points on the counter-efficiency vs. β -energy curve:

<u>Isotope</u>	<u>Energy</u> (mev)	<u>Half-Life</u>
C ¹⁴	.155	6x10 ³ yrs.
*Co ⁶⁰	.310	5.2 yrs.
Tl ²⁰⁴	.76	2.7 yrs.
*Na ²⁴	1.39	15 hrs.
P ³²	1.70	14.3 days

- * Co^{60} also emits γ -rays of 1.33, 1.7 and 2 mev; Na^{24} emits two γ -rays of 2.76 and 1.38 mev.

Standardization of the isotopes used was obtained as follows:

A solution of Cl^{35} , as standardized by the U.S. Bureau of Standards, was obtained from Dr. Sinex of the Medical Department.

A Co^{60} source was obtained by irradiating cobalt wire in the Brookhaven reactor. The wire was dissolved and the solution standardized by Dr. Cumming of the Chemistry Department, using a γ -coincidence method. Dr. Cumming's counters had been previously standardized using U.S. National Bureau of Standards calibrated sources.

A Tl^{204} calibrated solution of 5% accuracy was obtained from the U. S. National Bureau of Standards.

Several attempts to standardize a solution of Na^{24} , apparently none of them successful - were tried. In the first instance, irradiating NaCl in the pile was attempted. This resulted in the formation of S^{35} , from the reaction $\text{Cl}^{35}\text{-n p}$, which masked the Na^{24} activity. At a later date, NaNO_3 was irradiated; this reaction produced no contaminating isotopes but due to its short half life and high energy β^- , coupled with γ -ray emission, the sodium proved very difficult to work with. The β^- activity was impossible to filter out completely as the physical dimensions of the counter would not allow the insertion of a sufficiently thick aluminum absorber. Thus the γ -rays were never completely isolated. (For greater detail of this procedure see the method used for Co^{60}). In the light of the efficiencies obtained for P^{32} and Tl^{204} the estimated Na^{24} efficiency appears to be too low. Hence the Na^{24} results were discarded.

Since the figures obtained for the efficiencies of the flow counters were to be applied to the correction of routine samples, every effort was made to duplicate routine conditions as closely as possible.

A study of the dependence of the efficiencies of the counters on the geometry of the sample, using a point source, was made. The source was placed at various distances from the center of the shelf, both in the plane of the counter loop and at right angles to it. The results of the study are shown in Figures 12-14.

From Figures 12-14 it can be seen that in the plane of the loop there is approximately no geometry dependence until a radius of 0.3 inches is reached. In the plane perpendicular to the plane of the loop the curves are of a parabolic shape.

These results are not in agreement with Nader, Hagee, and Setter (22) who show a curve for relative counting rate vs. distance from center in a plane perpendicular to the wire loop. Using an operating voltage corresponding to the mid-point of an extended source plateau, they get geometry independence until a displacement of 1 inch from the center is reached.

In view of the fact that the radius of a routine sample is .625 inches, in order to avoid a geometry correction factor the identical planchets that are used for routine samples were employed for mounting the sources. At the same time, the same backscattering factor was insured for both source and sample.

Any self-absorption that may have occurred in the samples was not taken into consideration since its value is unknown and presumed negligible. The

procedure followed was to keep the source a thin film over the surface of the planchet and consider samples and sources infinitely thin emitters. The amount of source solution necessary to yield about 5000 counts per minute was determined, and aliquots were removed from the calibrated solution by means of an automatically controlled 20 λ pipette, and evaporated on the planchet above an infrared lamp. The sources were then counted and the efficiency of the counter calculated for the energy in question as shown below:

$$\text{Efficiency} = 100 \times \frac{\text{Average number of counts per min per ml above Bkgd}}{\text{Activity of source per min per ml as calibrated}} \dots\dots(1)$$

At least three aliquots were taken from each solution and the efficiencies were estimated as being **correct to within $\pm 5\%$** .

In the case of isotopes which were γ emitters as well as β^- emitters the procedure outlined in the text above was required to subtract the γ background from the counting rate obtained with zero absorber.

Table 1

<u>Isotope</u>	<u>Counter Number</u>	<u>Efficiency</u>
C14	F-1	42.4%
	F-2	44.9%
	F-3	44.8%
Co60 +	F-1	52.7%
	F-2	53.7%
	F-3	55.1%
Tl204	F-1*	70.5%
	F-2	73.6%
	F-3	74.0%
Na24 +	F-1	56.5%
	F-2	59.8%
	F-3	60.8%
P32	F-1	64.1%
	F-2	66.0%
	F-3	68.1%

+ These isotopes are also gamma emitters and the efficiencies have been corrected as well as possible.

* Recently, it was found that the F-1 plateau had shifted in the midst of this study and the true Tl²⁰⁴ efficiency is 74.5%.

These results are shown graphically in Figures 15-17.

Evaluation of Results

According to P. B. Burt and Nager, Hagee and Setter (22), the back-scattering factor for aluminum in the range of the plateau is 1.3. From this figure a plateau efficiency of 65% would be expected. As can be seen from

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Figures 4-6, the respective plateau efficiencies for F-1, F-2 and F-3 are 67%, 69.5% and 71.0%.

As these results are higher than expected, it was decided to test if the stainless steel floor was contributing to the backscattering factor. Accordingly, a 279 mg/cm² Al absorber was placed underneath the Al planchet and the Tl sources recounted.

The following results were obtained:

Counter F-1	72.5% efficiency
F-2	73.8% "
F-3	73.5% "

Since the atomic number of stainless steel is higher than that of aluminum, one would expect that the efficiencies would decrease as the backscattering is proportional to the atomic number of the scatterer. This is true in the case of F-3, but not for F-1 and F-2. Hence, it is possible that since by placing the sample on an absorber the distance between the loop and sample is decreased, the electric field is increased. In that case the counter would give a higher count and counteract the effect of a backscatterer of lowered Z if any.

As a check on how well the "ideal source" determined efficiencies correlate with the results obtained in practice the following procedure was adopted. Four evenly distributed routine samples with an appreciable count were selected. Each sample was counted in each of the flow counters. The efficiency correction factor as determined from the Thallium standard (23) was applied to each counter.* The statistical error in each count was calculated as described in the text above.

An error of about 1% was predetermined by counting the samples for an appropriate length of time.

Table 2

Efficiency Counter	No. 876 c/m	No. 875 c/m	No. 850 c/m	No. 811 c/m
(upper limit)	2121	525	1277	2132
70.5% F-1	2098±23.3 (1.1%)	519±5.8 (1.1%)	1268±8.8 (.69%)	2112±20.2 (.96%)
(lower limit)	2075	513	1259	2092
(upper limit)	2153	528	1263	2108
73.6% F-2	2133±19.7 (.92%)	522±5.7 (1.08%)	1253±9.9 (.79%)	2088±19.7 (.95%)
(lower limit)	2113	516	1243	2068
(upper limit)	2117	511	1261	2099
74.0% F-3	2097±19.6 (.93%)	505±5.6 (1.1%)	1249±12.4 (.99%)	2080±19.2 (.92%)
(lower limit)	2077	499	1237	2061

* The reason the Thallium standard was selected was because it was the only isotope that did not involve an additional error due to standardization by
(continued bottom of page II-5)

In this case all the counts, except sample No. 875 as counted in counter No. 3, fall within the statistical error. This indicates that the ratios of the efficiencies for the counters are good to considerably less than 1%. Actual calculations indicate that the error in these ratios is of the order of about $\pm 0.3\%$. Therefore, even if the calibration of the source is in error by some indeterminate amount, the relative response of the counters is not affected and they can be used interchangeably. This also indicates the suitability of Thallium²⁰⁴ as a standard.

The same procedure was repeated counting all samples over the aluminum absorber and using the efficiencies listed above for these conditions; the results are shown in Table 3.

Table 3

Eff.	Counter	No. 876 c/m	No. 875 c/m	No. 850 c/m	No. 811 c/m
72.5%	(upper limit)	2040	485	1244	2008
	F-1	2021 $\pm$ 19.4 (.96%)	480 $\pm$ 5.4 (1.1%)	1233 $\pm$ 12.4 (1.0%)	1989 $\pm$ 19.4 (.98%)
	(lower limit)	2002	475	1221	1970
73.8%	(upper limit)	2149	511	1245	2081
	F-2	2129 $\pm$ 19.7 (.93%)	505 $\pm$ 5.7 (1.1%)	1234 $\pm$ 12.3 (1.0%)	2062 $\pm$ 19.4 (.94%)
	(lower limit)	2109	499	1222	2043
73.5%	(upper limit)	2085	498	1244	2090
	F-3	2065 $\pm$ 19.5 (.94%)	493 $\pm$ 5.3 (1.1%)	1233 $\pm$ 12.3 (1.0%)	2070 $\pm$ 19.5 (.94%)
	(lower limit)	2045	488	1221	2050

From Table 3, it can be seen that in the great majority of cases, the counts, as corrected for the efficiency of the counter, do not fall within the expected deviation. This, and also the fact that the counters do not seem to count as consistently as before, would indicate that this use of the aluminum absorber is no improvement.

Comparison of RaD and E and Thallium as a Standard

Since the counter efficiencies occasionally vary with time, it has been necessary in the past to develop a quick and simple method of checking efficiencies periodically. The method adopted in the past has been to use calibrated sources in the form of RaD and E electroplated on a palladium backing.

The objection to the use of RaD and E⁺ as a standard are the following:

- 1) The RaD and E is mounted on palladium and a conversion factor must be used to compensate for the difference in the backscattering factors for palladium and aluminum.

* (continued from II-4)

another department on site. Tl²⁰⁴ is also a pure β^- emitter, its energy falls on the plateau and is approximately the same as that due to fission products; the latter are the main composition of many of the routine samples (23).

- 2) The RaD and E source is in the shape of a thin disk of about $1/8$ " radius in comparison to a routine sample which is spread over the bottom of a $5/8$ " radius planchet. Furthermore, the planchet has a rim with a lip, while the RaD and E source is flush with its backing.
- 3) Since RaD and E emits an α -ray when decaying into RaF, the β^- activity determination of the source is complicated unless the α -rays are filtered out. For this purpose, aluminum absorbers are used and an absorption curve of counts per minute against absorber thickness is plotted. If a log scale is used for the ordinate, the curve is a straight line past a minimum absorber thickness.

The minimum absorber thickness that will filter out the α -rays has been experimentally determined as 6 mg/cm^2 . Although it is known that as the curve approaches the ordinate axis it becomes concave upward, a method of fitting a straight line to the first fifteen points obtained was nevertheless adopted. This method was not expected to yield an absolute β^- efficiency but, rather, it was hoped than an intercomparison of counter performances would be realized. Furthermore, the method could be handled as a routine procedure.

An alternative method of analyzing the absorption curve was to actually extrapolate the curve back to zero absorber thickness, estimating its curvature from the experimentally determined points. This method could yield absolute efficiencies, but it is subject to considerable error in the extrapolation and could not be routinized as easily. Also the geometry and backscattering factors are unknown. The three absorption curves as obtained for F-1, F-2 and F-3 respectively are shown in Figures 18, 19, 20.

A straight line was also fitted to each set of points by the least-squares technique and the counter efficiencies calculated as described in Appendix I. The latter efficiencies were applied to the routine samples selected for Table 3 and the results shown in Table 4.

Table 4
Using RaD and E efficiencies

<u>Eff.</u>	<u>Counter</u>	<u>No. 876</u>	<u>No. 875</u>	<u>No. 850</u>	<u>No. 811</u>
42.6%	F-1	3512 3474 $\pm$ 38.2 (1.1%) 3436	870 860 $\pm$ 9.5 (1.1%) 850	2114 2099 $\pm$ 14.5 (.69%) 2084	3529 3495 $\pm$ 33.6 (.96%) 3461
42.0%	F-3	3699 3665 $\pm$ 34.1 (.93%) 3631	893 883 $\pm$ 9.7 (1.1%) 873	2203 2181 $\pm$ 21.6 (.99%) 2169	3697 3664 $\pm$ 33.0 (.92%) 3631
42.5%	F-2	3775 3741 $\pm$ 34.4 (.92%) 3707	914 904 $\pm$ 9.8 (1.08%) 894	2186 2169 $\pm$ 17.1 (.79%) 2152	3647 3614 $\pm$ 34.3 (.95%) 3580

* RaD and E has a maximum β^- energy of 1.17 mev. and hence it falls on the plateau of the counter efficiency vs. β^- energy curve.

Table 5 below summarizes the efficiency calculations used in Table 4.

Table 5

<u>Counter</u>	<u>R₀*</u>	<u>D/M for Standard Source</u>	<u>Efficiency</u>
F-1	6,166	11,262	42.6%
F-2	6,082	11,124	42.5%
F-3	6,102	11,202	42.0%

* Multiplied by .777 to correct for the difference in backscattering material.

As can be seen from Figures 15, 16 and 17, these efficiencies fall far below those determined with the standardized sources. The efficiencies should have been in the neighborhood of 70%.

As far as intercomparison of counter efficiencies, these also do not fall within the statistical error as may be seen from Table 5.

Since it is known that the absorption curves are not actually straight lines, Figures 18, 19 and 20 were carefully extrapolated to zero absorber. Unfortunately, as can be seen from the figures there is a wide range of error in this graphical method. The results are shown below, taking the difference in backscattering factor into account.

Table 7

<u>Counter</u>	<u>Extrapolated Efficiency</u>	<u>Graphical Upper Limit</u>	<u>Graphical Lower Limit</u>
F-1	55.5% ^{+6.7} _{-4.2}	62.2%	51.3%
F-2	58.3% ^{+10.7} _{- 4.5}	69.0%	53.8%
F-3	58.3% ^{+11.1} _{- 3.5}	69.4%	54.8%

Even though the upper limits of extrapolation check favorably with those expected from Figures 15, 16 and 17, this method is too subject to error to be of any practical use.

III. Recommendation for a Standard to be used in Calibration of Future Efficiencies of Counters

Since the efficiencies of the counters, as obtained by fitting a straight line to the RaD and E absorption curve, fall far below the expected value, and also do not give the correct inter-counter ratio, it is recommended that this method be discontinued.

Since extrapolation of the absorption curves is subject to as much as a 14% error, and gives no information as to the ratios of counter efficiencies, this method is also not practical.*

An attempt was made to find some conversion factor that could be used to multiply a point on the RaD and E absorption curve to give the efficiency of the counter as found by the Thallium source. Unfortunately, this factor is different for every counter and consequently, would have to be found experimentally in each case.

In view of these facts and those brought out in the body of the report, it is recommended that several Thallium standardized sources be prepared and used as standards for determining the flow-counter efficiencies in the future. The strength of the sources should be about 8,000 c/min. In order to insure permanance of the source, a thin preservative film will be sprayed or deposited over the surface and any absorption by the film taken into account.

Since Tl^{204} has a half-life of 2.7 years a chart to 3 place accuracy correcting for the decay of the isotope is included below.

- * At any rate, the efficiencies as gotten for the RaD and E source and the Thallium standard, can not be expected to agree, even assuming the same geometry. This is due to the difference in β^- spectrum of the two isotopes. Thallium is a typical β^- emitter with an average energy approximately equal to .40 E max. while RaD and E has been shown to have an average energy of .28 E max. See Upson, "Evaluating Beta Energy Dependence in End Window G.M. Tubes", Nucleonics, December, 1953.

Table 6

Correction for Tl^{204} decay $T_{1/2} = 2.7$ yrs. 985.5 days

days t	$e^{-\lambda t}$	days t	$e^{-\lambda t}$	days t	$e^{-\lambda t}$
1	.999	51	.965	101	.931
2	.999	52	.964	102	.931
3	.998	53	.963	103	.930
4	.997	54	.963	104	.930
5	.997	55	.962	105	.929
6	.996	56	.961	106	.928
7	.995	57	.961	107	.928
8	.994	58	.960	108	.927
9	.994	59	.959	109	.926
10	.993	60	.959	110	.926
11	.992	61	.958	111	.925
12	.992	62	.957	112	.924
13	.991	63	.957	113	.924
14	.990	64	.956	114	.923
15	.990	65	.955	115	.922
16	.989	66	.955	116	.922
17	.988	67	.954	117	.921
18	.988	68	.953	118	.920
19	.987	69	.953	119	.920
20	.986	70	.952	120	.919
21	.985	71	.951	121	.919
22	.985	72	.951	122	.918
23	.984	73	.950	123	.917
24	.983	74	.949	124	.916
25	.983	75	.949	125	.916
26	.982	76	.948	126	.915
27	.981	77	.947	127	.915
28	.981	78	.947	128	.914
29	.980	79	.946	129	.913
30	.979	80	.945	130	.913
31	.979	81	.945	131	.912
32	.978	82	.944	132	.911
33	.977	83	.943	133	.911
34	.976	84	.943	134	.910
35	.976	85	.942	135	.909
36	.975	86	.941	136	.909
37	.974	87	.941	137	.908
38	.974	88	.940	138	.908
39	.973	89	.939	139	.907
40	.972	90	.939	140	.906
41	.972	91	.938	141	.906
42	.971	92	.937	142	.905
43	.970	93	.937	143	.904
44	.970	94	.936	144	.904
45	.969	95	.935	145	.903
46	.968	96	.935	146	.902
47	.968	97	.934	147	.902

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days t	e ^{-λt}	days t	e ^{-λt}	days t	e ^{-λt}
48	.967	98	.933	148	.901
49	.966	99	.933	149	.901
50	.965	100	.932	150	.900
151	.899	201	.868	251	.838
152	.899	202	.868	252	.838
153	.898	203	.867	253	.837
154	.897	204	.866	254	.836
155	.897	205	.866	255	.836
156	.896	206	.865	256	.835
157	.895	207	.865	257	.835
158	.895	208	.864	258	.834
159	.894	209	.863	259	.834
160	.894	210	.863	260	.833
161	.893	211	.862	261	.832
162	.892	212	.862	262	.832
163	.892	213	.861	263	.831
164	.891	214	.860	264	.831
165	.890	215	.860	265	.830
166	.890	216	.859	266	.829
167	.889	217	.858	267	.829
168	.889	218	.858	268	.828
169	.888	219	.857	269	.828
170	.887	220	.857	270	.827
171	.887	221	.856	271	.827
172	.886	222	.855	272	.826
173	.886	223	.855	273	.825
174	.885	224	.854	274	.825
175	.884	225	.854	275	.824
176	.884	226	.853	276	.824
177	.883	227	.852	277	.823
178	.882	228	.852	278	.823
179	.882	229	.851	279	.822
180	.881	230	.851	280	.821
181	.881	231	.850	281	.821
182	.880	232	.850	282	.820
183	.879	233	.849	283	.820
184	.879	234	.848	284	.819
185	.878	235	.848	285	.818
186	.877	236	.847	286	.818
187	.877	237	.847	287	.817
188	.876	238	.846	288	.817
189	.876	239	.845	289	.816
190	.875	240	.845	290	.816
191	.874	241	.844	291	.815
192	.874	242	.844	292	.814
193	.873	243	.843	293	.814
194	.872	244	.842	294	.813
195	.872	245	.842	295	.813
196	.871	246	.841	296	.812
197	.871	247	.841	297	.812
198	.870	248	.840	298	.811
199	.869	249	.840	299	.810
200	.869	250	.839	300	.810

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days t	e $-\lambda t$	days t	e $-\lambda t$	days t	e $-\lambda t$
301	.809	351	.781	401	.754
302	.809	352	.781	402	.754
303	.808	353	.780	403	.753
304	.808	354	.780	404	.753
305	.807	355	.779	405	.752
306	.806	356	.779	406	.752
307	.806	357	.778	407	.751
308	.805	358	.777	408	.751
309	.805	359	.777	409	.750
310	.804	360	.776	410	.750
311	.804	361	.776	411	.749
312	.803	362	.775	412	.749
313	.803	363	.775	413	.748
314	.802	364	.774	414	.748
315	.801	365	.774	415	.747
316	.801	366	.773	416	.746
317	.800	367	.773	417	.746
318	.800	368	.772	418	.745
319	.799	369	.772	419	.745
320	.799	370	.771	420	.744
321	.798	371	.770	421	.744
322	.797	372	.770	422	.743
323	.797	373	.769	423	.743
324	.796	374	.769	424	.742
325	.796	375	.768	425	.742
326	.795	376	.768	426	.741
327	.795	377	.767	427	.741
328	.794	378	.767	428	.740
329	.794	379	.766	429	.740
330	.793	380	.766	430	.739
331	.792	381	.765	431	.739
332	.792	382	.765	432	.738
333	.791	383	.764	433	.738
334	.791	384	.763	434	.737
335	.790	385	.763	435	.737
336	.790	386	.762	436	.736
337	.789	387	.762	437	.736
338	.789	388	.761	438	.735
339	.788	389	.761	439	.734
340	.787	390	.760	440	.734
341	.787	391	.760	441	.733
342	.786	392	.759	442	.733
343	.786	393	.759	443	.732
344	.785	394	.758	444	.732
345	.785	395	.758	445	.731
346	.784	396	.757	446	.731
347	.784	397	.757	447	.730
348	.783	398	.756	448	.730
349	.782	399	.755	449	.729
350	.782	400	.755	450	.729

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days t	e - λ t	days t	e - λ t	days t	e - λ t
451	.728	501	.703	551	.679
452	.728	502	.703	552	.678
453	.727	503	.702	553	.678
454	.727	504	.702	554	.677
455	.726	505	.701	555	.677
456	.726	506	.701	556	.676
457	.725	507	.700	557	.676
458	.725	508	.700	558	.676
459	.724	509	.699	559	.675
46-	.724	510	.699	56-	.675
461	.723	511	.698	561	.674
462	.723	512	.698	562	.674
463	.722	513	.697	563	.673
464	.722	514	.697	564	.673
465	.721	515	.696	565	.672
466	.721	516	.696	566	.672
467	.720	517	.695	567	.671
468	.720	518	.695	568	.671
469	.719	519	.694	569	.670
470	.719	520	.694	570	.670
471	.718	521	.693	571	.669
472	.718	522	.693	572	.669
473	.717	523	.692	573	.668
474	.717	524	.692	574	.668
475	.716	525	.691	575	.668
476	.716	526	.691	576	.667
477	.715	527	.690	577	.667
478	.715	528	.690	578	.666
479	.714	529	.689	579	.666
480	.714	530	.689	580	.665
481	.713	531	.688	581	.665
482	.713	532	.688	582	.664
483	.712	533	.687	583	.664
484	.712	534	.687	584	.663
485	.711	535	.687	585	.663
486	.711	536	.686	586	.662
487	.710	537	.686	587	.662
488	.710	538	.685	588	.661
489	.709	539	.685	589	.661
490	.709	540	.684	590	.660
491	.708	541	.684	591	.660
492	.708	542	.683	592	.660
493	.707	543	.683	593	.659
494	.707	544	.682	594	.659
495	.706	545	.682	595	.658
496	.706	546	.681	596	.658
497	.705	547	.681	597	.657
498	.705	548	.680	598	.657
499	.704	549	.680	599	.656
500	.704	550	.679	600	.656

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days t	e $-\lambda t$	days t	e $-\lambda t$	days t	e $-\lambda t$
601	.655	651	.633	701	.611
602	.655	652	.632	702	.610
603	.655	653	.632	703	.610
604	.654	654	.631	704	.610
605	.654	655	.631	705	.609
606	.653	656	.631	706	.609
607	.653	657	.630	707	.608
608	.652	658	.630	708	.608
609	.652	659	.629	709	.608
610	.651	660	.629	710	.607
611	.651	661	.628	711	.607
612	.650	662	.628	712	.606
613	.650	663	.627	713	.606
614	.649	664	.627	714	.605
615	.649	665	.627	715	.605
616	.649	666	.626	716	.605
617	.648	667	.626	717	.604
618	.648	668	.625	718	.604
619	.647	669	.625	719	.603
620	.647	670	.624	720	.603
621	.646	671	.624	721	.602
622	.646	672	.624	722	.602
623	.645	673	.623	723	.602
624	.645	674	.623	724	.601
625	.644	675	.622	725	.601
626	.644	676	.622	726	.600
627	.644	677	.621	727	.600
628	.643	678	.621	728	.599
629	.643	679	.620	729	.599
630	.642	680	.620	730	.599
631	.642	681	.619	731	.598
632	.641	682	.619	732	.598
633	.641	683	.619	733	.597
634	.640	684	.618	734	.597
635	.640	685	.618	735	.596
636	.639	686	.617	736	.596
637	.639	687	.617	737	.596
638	.639	688	.617	738	.595
639	.638	689	.616	739	.595
640	.638	690	.616	740	.594
641	.637	691	.615	741	.594
642	.637	692	.615	742	.594
643	.636	693	.614	743	.593
644	.636	694	.614	744	.593
645	.635	695	.613	745	.592
646	.635	696	.613	746	.592
647	.634	697	.613	747	.591
648	.634	698	.612	748	.591
649	.634	699	.612	749	.591
650	.633	700	.611	750	.590

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days t	e - λ t	days t	e - λ t	days t	e - λ t
751	.590	800	.570	850	.550
752	.589	801	.569	851	.550
753	.589	802	.569	852	.549
754	.589	803	.569	853	.549
755	.588	804	.568	854	.549
756	.588	805	.568	855	.548
757	.587	806	.567	856	.548
758	.587	807	.567	857	.547
759	.586	808	.567	858	.547
760	.586	809	.566	859	.547
761	.586	810	.566	860	.546
762	.585	811	.565	861	.546
763	.585	812	.565	862	.546
764	.584	813	.565	863	.545
765	.584	814	.564	864	.545
766	.584	815	.564	865	.544
767	.583	816	.563	866	.544
768	.583	817	.563	867	.544
769	.582	818	.563	868	.543
770	.582	819	.562	869	.543
771	.582	820	.562	870	.542
772	.581	821	.561	871	.542
773	.581	822	.561	872	.542
774	.580	823	.561	873	.541
775	.580	824	.560	874	.541
776	.580	825	.560	875	.541
777	.579	826	.560	876	.540
778	.579	827	.559	877	.540
779	.578	828	.559	878	.539
780	.578	829	.558	879	.539
781	.578	830	.558	880	.539
782	.577	831	.558	881	.538
783	.577	832	.557	882	.538
784	.576	833	.557	883	.538
785	.576	834	.556	884	.537
786	.576	835	.556	885	.537
787	.575	836	.556	886	.536
788	.575	837	.555	887	.536
789	.574	838	.555	888	.536
790	.574	838	.554	889	.535
791	.573	840	.554	890	.535
792	.573	841	.554	891	.535
793	.573	842	.553	892	.534
794	.572	843	.553	893	.534
795	.572	844	.553	894	.533
796	.571	845	.552	895	.533
797	.571	846	.552	896	.533
798	.571	847	.551	897	.532
799	.570	848	.551	898	.532
		849	.551	899	.532

days t	$e^{-\lambda t}$	days t	$e^{-\lambda t}$
900	.531	950	.513
901	.531	951	.512
902	.530	952	.512
903	.530	953	.512
904	.530	954	.511
905	.529	955	.511
906	.529	956	.511
907	.529	957	.510
908	.528	958	.510
909	.528	959	.510
910	.527	960	.509
911	.527	961	.509
912	.527	962	.508
913	.526	963	.508
914	.526	964	.508
915	.526	965	.507
916	.525	966	.507
917	.525	967	.507
918	.524	968	.506
919	.524	969	.506
920	.524	970	.506
921	.523	971	.505
922	.523	972	.505
923	.523	973	.505
924	.522	974	.504
925	.522	975	.504
926	.522	976	.504
927	.521	977	.503
928	.521	978	.503
929	.520	979	.503
930	.520	980	.502
931	.520	981	.502
932	.519	982	.501
933	.519	983	.501
934	.519	984	.501
935	.518	985	.500
936	.518		
937	.518		
938	.517		
939	.517		
940	.516		
941	.516		
942	.516		
943	.515		
944	.515		
945	.515		
946	.514		
947	.514		
948	.514		
949	.513		

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Figure 1. Alpha Scintillation Counter.

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Figure 2. Alpha scintillation counter, crosssectional view.

Figure 3a.

INSTRUMENT DEVELOPMENT
LABORATORIES
MODEL 161
SCALING CIRCUIT

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Figure 3b. Modification of Model 161 Scaler for Predetermined Time.
(See Figure 3a)

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Figure 4a.

SCALING UNIT MODEL 162

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495 055

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Figure 4b. Predetermined Time Modification for Scaler Model 162.
(Figure 4a)

Figure 4c. Solenoid Connection for Use with Gas Flow Counters to Control Gas Flow and Flush Counters.

Figure 4d. Modification of Model 162 Scaler Preamplifier Circuit.

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Figure 4e. Modification¹ of Model 162 Scaler Output Stage
(Used with F-1 and F-2 Counters).

Figure 4f. Modification¹ of Model 162 Scaler Output Stage
(Used with F-3 Counter and Spare Scaler).

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Figure 4g (Above). Continuous Flow Proportional Counter with Scaling Unit and Timer.

Figure 4h (Right). Continuous Flow Proportional Counter Showing Hemisphere and Sliding Shelf.

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Figure 5. Continuous Flow Proportional Counter.

Figure 6.

nuclear instrument corporation

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SCALING UNIT MODEL 163

NOTE: Model 164 - same except stand-
ard register is used and S-3 is omitted

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Figure 7. Voltage Regulator Control Circuit.

Figure 8. Geiger-Muller End-Window Tube.

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Figure 9. A Typical Curve Showing the Effect of Beta Particle Energy on Counting Efficiency.

Figure 10a. Error in Counts per Minute as a Function of Total Count and Length of Count.

Figure 10b. Error in Counts per Minute as a Function of Total Count and Length of Count.

Figure 11. Beta Particle Range. (See Radiological Health Handbook Page 85 for More Complete Curve. Published by U.S. Department of Health, Public Health Services, Cincinnati, Ohio.)

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FIGURE 12

FLOW COUNTER F-1

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FIGURE 13

FLOW COUNTER F-2

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FIGURE 14

FLOW COUNTER F-3

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FIGURE 15

Flow - Counter F-1

435 067

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FIGURE 16

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FIGURE 17

495 069

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FIGURE 18

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FIGURE 19

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FIGURE 20

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Figure 21B. Model 111 Scaling Strip: Schematic Diagram.

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