# THE HALF-LIVES OF BISMUTH-215 AND BISMUTH-211, AND THE BRANCHING RATIO OF BISMUTH-211

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Thesis Approved:

Thesis Adviser

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# PREFACE

This endeavor is concerned with the measurement of some of the properties of the bismuth nuclides of the actinium series with improved precision. Both half-lives were measured and the alpha/beta branching ratio of bismuth-211 was also measured.

The author would like to express his deepest appreciation to Dr. Matti Nurmia for his invaluable guidance and his continuous encouragement, aid and assistance during the performance of this work. He is grateful also to Mr. D. F. Giessing for his assistance, especially with the chemical separations; to Dr. L. Vargo for aid in using the computer; and to Mr. G. D. Loper for his assistance. Recognition is also due to the Oklahoma State University Research Foundation to whom the author is grateful for financial assistance.

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# CHAPTER I

# INTRODUCTION

## The Actinium Series

The actinium series has as members isotopes with mass numbers given by 4n + 3, where n is an integer, ranging from 52 to 58. The radioactive decay in this series includes the emission of alpha particles of energies from about 4.1 MeV to 7.44 MeV and the emission of beta particles with energies ranging up to about 1.4 MeV.

The first member of the actinium series is uranium-235, Actinouranium, whose half-life is $6.8 \times 10^8$ years (1) and which decays by emission of alpha particles having energies from 4.1 to 4.6 MeV into thorium-231 (2). This nuclide has a half-life of 25.6 hours (3) and decays by beta-emission into protoactinium-231 which decays with a 34300 year half-life (4) by emission of alpha-particles of energies 4.66 to 5.05 MeV (5) to yield actinium-227. Since most laboratory sources for the actinium series come from an extraction of actinium-227 from nature, this element is often considered as being the parent isotope of the series.

98.6 per cent (6) of actinium-227, whose half-life is 22 years, decays by beta-emission into thorium-227. (Refer to Table I for detailed data and references.) By successive

alpha-emissions, thorium-227 decays to radium-223, radon-219, polonium-215 and lead-211. Lead-211 decays by beta-emission to bismuth-211 which mainly decays by alpha-emission to yield thallium-207. This isotope decays to stable lead-207 by beta-emission. This is the main branch of the actinium series.

The secondary branch begins with the emission of alpha-particles by 1.4 per cent of the actinium-227 (6), yielding francium-223, which decays primarily by beta-emission to radium-223, part of the main branch. However, $4 \times 10^{-5}$ of the francium-223 decays by alpha-emission to astatine-219 of which one-thirtieth beta-decays to radon-219 and of which the rest decays by alpha-emission to bismuth-215. This isotope beta-decays back to the main branch, yielding polonium-215.

Polonium-215, the end of the secondary branch of the series, is the beginning of another branch. A small portion, $5 \times 10^{-4}$, of the isotope decays by beta-emission to astatine-215 which alpha-decays back to bismuth-211, a member of the main branch. Bismuth-211 also branches, about 0.3 per cent decaying to 0.52 second half-life polonium-211, an alpha-emitter which yields stable lead-207.

The actinium series is illustrated in Figure 1. Arrows slanted upward represent beta-decay; the other arrows represent alpha-decay. Table I lists the modes of decay, energies, and branching ratios of nuclides in the

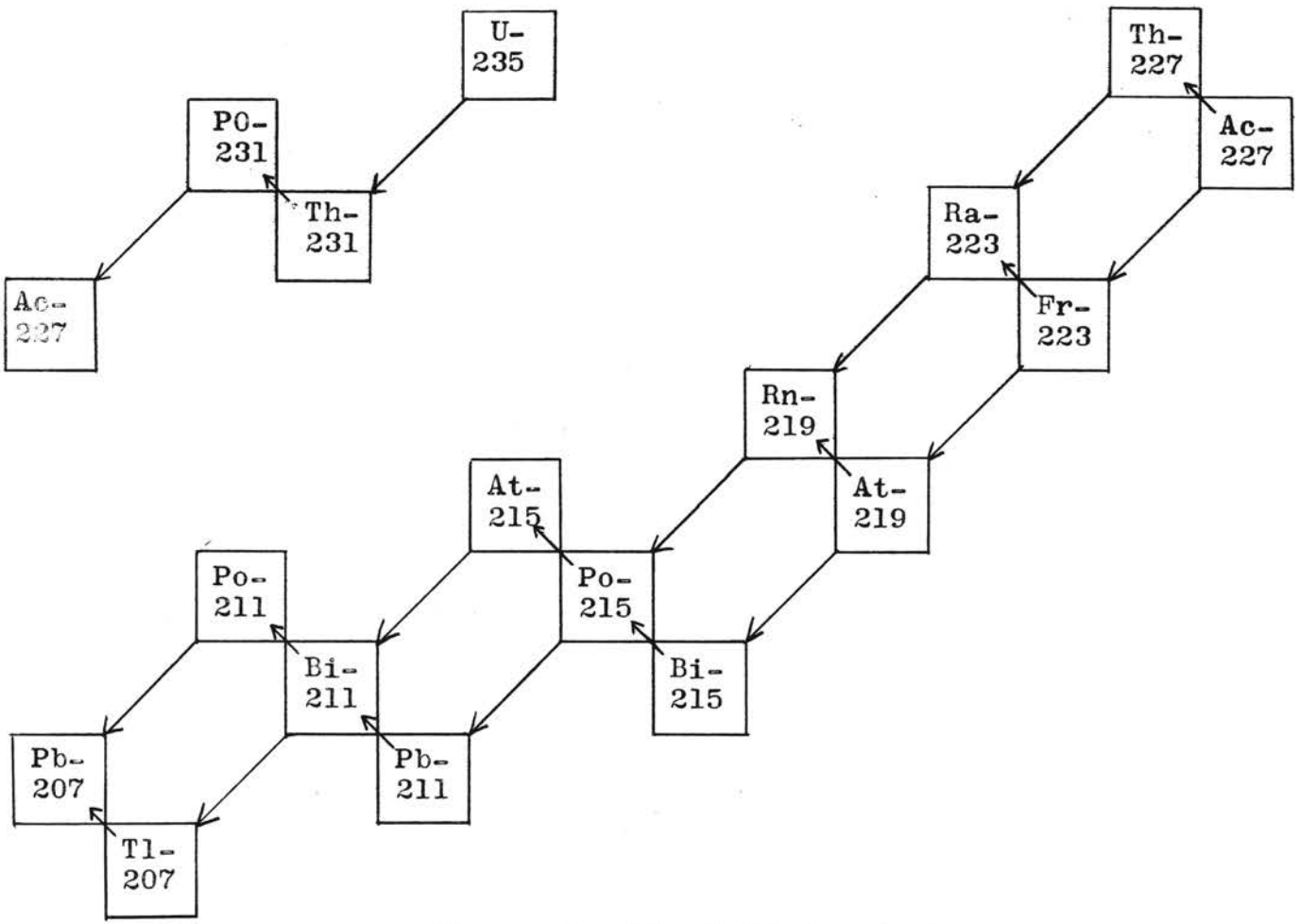


Figure 1. The Actinium Series

TABLE I

THE ACTINIUM SERIES(Beginning with Ac-227)

| Nuclide | Historical Name | Half-Life | Branching Ratio | Energy of Emitted Particles in MeV | |
|---|---|---|---|---|---|
| | | | | Alpha | Beta |
| Ac-227 | Actinium | 22y (7,8) | a 0.014(6) | 4.949,49%;4.9365,36%; 4.52-4.87,15%. (9) | 0.042-0.045(10) |
| Th-227 | Radio-actinium | 18.17d (11) | -- | 6.036,23%;5.976,24%; 5.755,21%;5.67-6.01,32%(12) | -- |
| Ra-223 | Actinium X | 11.7d (11) | -- | 5.712,50%;5.602,24%; 5.28-5.87,26% (12) | -- |
| Rn-219 | Ac Emanci-pation | 3.92s (13) | -- | 6.813,82%;6.547,13%; 6.419,5%. (12,14,15) | -- |
| Po-215 | Actinium A | 1.83ms(16) | b $5 \cdot 10^{-4}$ (17,18) | 7.36 or 7.38 (12,14) | ? (17,18) |
| Pb-211 | Actinium B | 36.1m(19,20) | -- | -- | 0.56-1.39(21,22) |
| Bi-211 | Actinium C | 2.16m(20,22) | b 0.32%(20) | 6.617,83%;6.273,17% (1,23,24) | 0.60 |
| Tl-207 | Actinium C" | 4.8m (25) | -- | -- | 1.44,99.8%;0.55, 0.2%(27) |
| Fr-223 | Actinium K | 22m(28,29) | a $6 \cdot 10^{-5}$ (28,29) | 5.34-0.08 (28,29) | 1.0-1.2 (30,31) |
| At-219 | -- | 0.9-0.1m(32) | a 30 (32) | 6.27 (32) | ? (32) |

TABLE I (CONTINUED)

| Nuclide | Historical Name | Half-Life | Branching Ratio | Energy of Emitted Particles in MeV | |
|---|---|---|---|---|---|
| | | | | Alpha | Beta |
| Bi-215 | -- | 8-2m (32) | -- | -- | ? (32) |
| At-215 | -- | 0.1ms (33) | -- | 8.00 (18,33) | -- |
| Po-211 | Actinium C' | 0.52s (22) | -- | 7.44,99%;6.57,0.5%; 6.90,05% (34) | -- |
| Pb-207 | Actinium D | Stable | -- | -- | -- |

actinium series, excluding isotopes coming before actinium-227.

Figure 2 is a plot of the alpha spectrum of a source which contains the actinium series (from actinium-227 onward) in equilibrium.

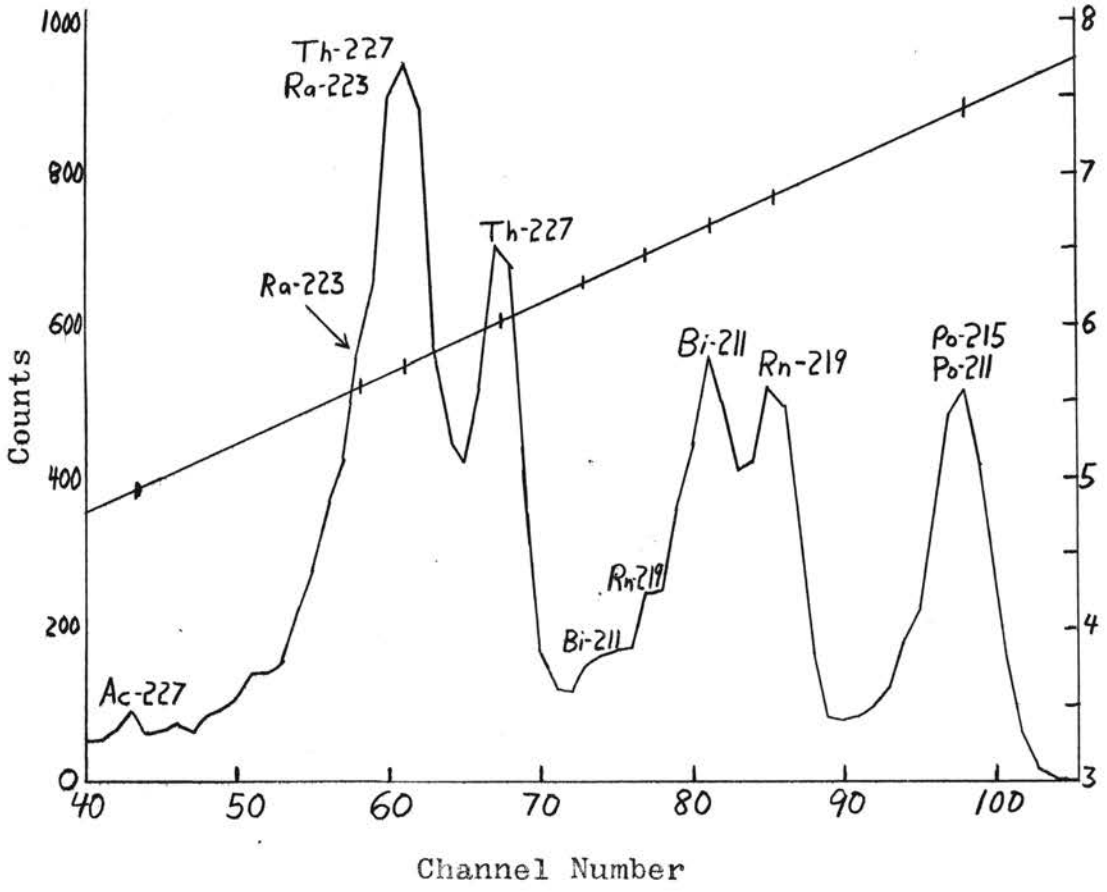


Figure 2. Spectrum of Actinium Series in Equilibrium.

## Later Elements in the Series

The lower end of the actinium series has several branches, of which not all have been known until relatively recently. Much of the data in this region is rather new and some of it is also rather inaccurate. Several of the decays in this region will be discussed in more detail here and notice will be made of certain cases for which data is not known accurately or is of interest for other reasons.

In 1953 Hyde and Ghiorso (32) established that francium-223 is an alpha-emitter with a branching ratio of $4.10^{-5}$, producing astatine-219, a new member of the series. They extracted astatine from a hydrochloric acid solution of francium into a solution of tributyl phosphate in butyl ether. Alpha particles from polonium-215 and a very few from radon-219 were observed. To observe the alpha-particles from astatine-219 directly, a faster volatilization separation was used to extract astatine. Hyde and Ghiorso also established that the half-life of astatine-219 is $0.9 \pm 0.1$ minutes and estimated the alpha-particles having an energy of 6.27 MeV and left as a product bismuth-215, a new nuclide. Bismuth-215 was found to be a beta-emitter with a half-life of $8 \pm 2$ minutes. The beta decay products of astatine-219 and bismuth-215 are radon-219 and polonium-215, respectively, both members of the main branch of the series.

The alpha daughter of polonium-215 is lead-211, a 36.1 minute half-life beta-emitter (19, 20), which yields

bismuth-211, most of whose alpha-particles have an energy of 6.613 MeV (12). This nuclide also is beta-active with a branching ratio of 0.32 per cent (20), yielding the 0.52-second ground state of polonium-211 (22), which emits 7.44 MeV alpha-particles (34).

This investigator, having at his disposal most of the necessary constituents of an alpha spectrometry system, decided to attempt to improve the data in as many cases as feasible.

Ionization chamber alpha-spectrometry, as will be explained later, yields relative energies of alpha-particles and yields the alpha-activities corresponding to the various alpha-energies.

The following measurements were selected as being feasible: the half-lives of astatine-219 and bismuth-215, by observing alpha pulses from the short-lived daughter nuclide polonium-215; and the half-life and branching ratio of bismuth-211. Bismuth-211 alpha-activity was used for its half-life; the alpha activity of short-lived polonium-211 was used as the measure of bismuth-211 beta-activity.

The use of polonium isotopes to determine the beta-activities of their parent bismuth isotopes was possible because of the extremely short half-lives of both polonium-215 and polonium-211. An astatine extraction would give a bismuth-215 activity growing towards the initial astatine-219 activity with a slope which was the same, except for sign, as the slope of the astatine decay, until bismuth-215

decay becomes significant. Thus polonium-215 activity could conceivably be used to determine the half-life of astatine-219 also.

A key problem arises from the similarity of the energies of polonium-215 and polonium-211 (See Table 1). These differ by less than 0.1 MeV. Activities from these isotopes cannot be clearly distinguished and this fact was a limiting factor in attempts to make accurate measurements in this endeavor.

## CHAPTER II

## APPARATUS

The alpha activities were studied using an ionization chamber apparatus as shown below.

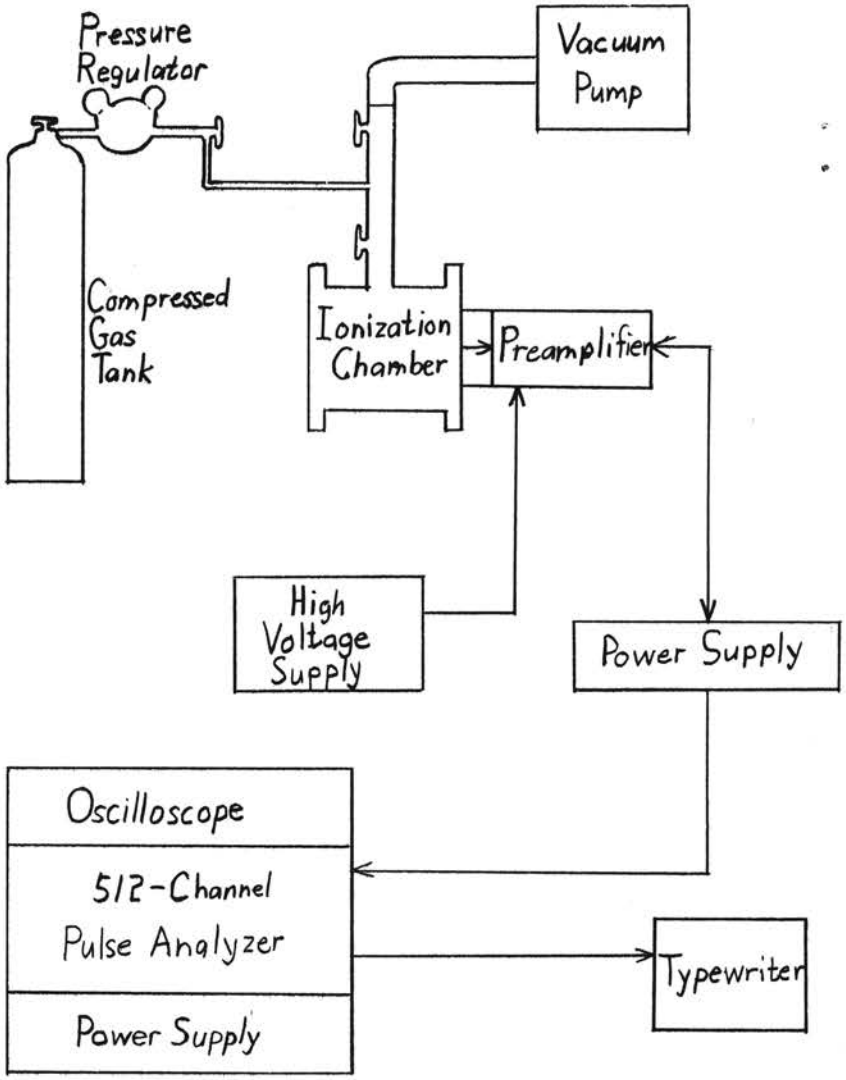


Figure 3. Apparatus

The alpha-pulses were produced in gridded parallel-plate ionization chambers similar to those described by Karras (35) and Nurmia (36). Each chamber was made of brass in a cylindrical shape with a 12.0 cm. inside diameter and 14.0 cm. inside height (see Figure 4).

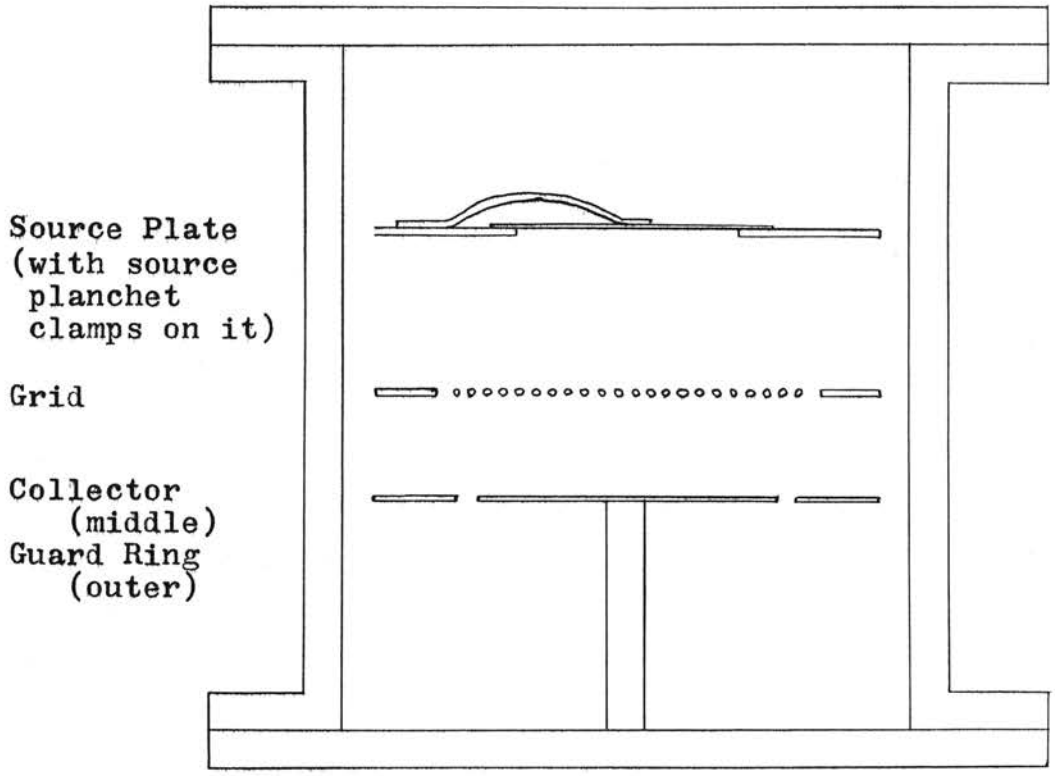


Figure 4. Sketch of the Cross-Sectional View of the Principal Parts of an Ionization Chamber.

The collector, which was 7.6 cm. in diameter, was attached to one end of the chamber (this end will be called the bottom hereafter) using a lucite rod 5.2 cm. long. This collector plate was surrounded by a guard ring. The source plate, grid, and guard ring were each about 11.2 cm. in diameter and were supported by three small rods extending

up from the bottom of the chamber. Each rod was surrounded by a small glass tube for insulation and by larger glass tubing which served as spacers. These spacers separated the source plate, the grid, and the guard ring. Each of the electrodes were connected to outside terminals by means of feed-through insulators.

The wires in the grid windings were about 0.25 cm. apart. The grid was 1.96 cm. from the source and 1.28 cm. from the collector.

The collector potentials used varied from 900 to 1200 volts, depending on certain conditions such as humidity. This potential was supplied by the high-voltage supply of a scaler (Model DV-1, B-J Electronics). A voltage-divider circuit (see Figure 5) was used to maintain the grid at one-half the potential of the collector.

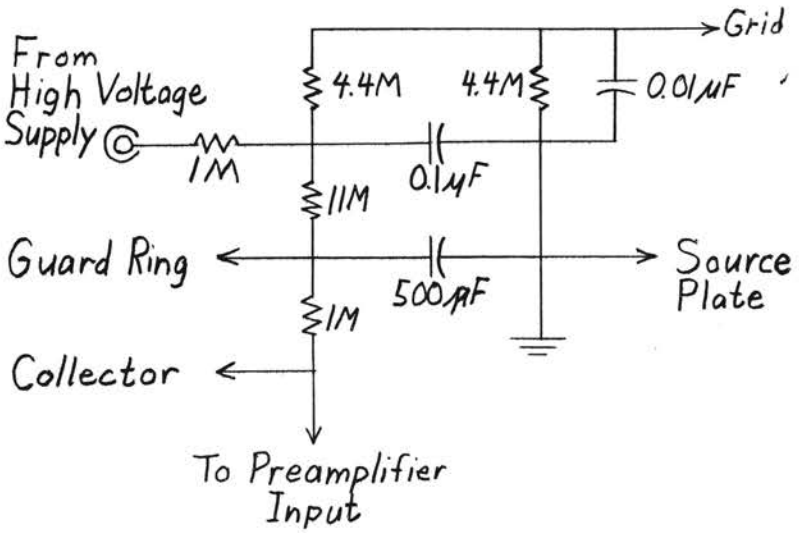


Figure 5. Voltage-divider Circuit

The chamber filling used was a commercial mixture of 90 per cent argon and ten per cent methane at a gage pressure of 2.1 atmospheres. The chamber end-plates were fastened with six screws apiece to facilitate easy access to the inside of the chamber. O-rings were used to seal the ends.

After some use the ionization chambers became radioactively contaminated, causing a background problem. To minimize this problem several steps were taken. A metallic shield was mounted under the collector to stop radiation from the bottom of the chamber. The walls and the top of the chamber were lined with paper to keep alpha-particles from these locations from reaching the sensitive region of the ionization chamber, that region between the source plate and the grid. Source plates, grids, collectors, and guard rings were replaced by spares whenever they became seriously contaminated.

An opening on one side of each chamber was connected to a series of two valves. As can be seen in Figure 2, after attaching the hose from a vacuum pump to the pipe beyond the second valve, the chamber could be evacuated. Then with the second valve closed ( and the first valve still open) the chamber could be filled with the argon-methane mixture to the desired pressure, which was controlled by the pressure-regulating device attached to the gas cylinder.

A faster process, "flushing," could be used instead, or in conjunction with, the use of the vacuum pump. Both

valves are opened and the gas tube from the cylinder is pinched shut. After most of the pressure has escaped from the chamber the second valve is closed and the tube is released, allowing the chamber to be filled. The whole operation is repeated several times.

The process by which an alpha-particle ionizes a gas and loses energy is well known. (See, for example, Kaplan, Chapter 13.) (37) The range of alpha-particles emitted from the source in an ionization chamber is short enough that they are stopped before leaving the chamber's sensitive region between the source plate and the grid. Before stopping, an alpha-particle will ionize a number of atoms, the number being proportional to the energy of the alpha-particle. The resulting electron cloud is accelerated downward by the electric field due to the grid towards the collector. As the collector receives this cloud, a negative pulse is formed with a rise time of almost one microsecond and a height proportional to the alpha-particle energy. This pulse is fed directly to the preamplifier input as shown in Figure 5.

The preamplifier, shown in Figure 6, is a modification of a Tennelec Model 100A Low Noise Preamplifier, using essentially the first stage. It is a cascode feedback amplifier, having an amplification of about 110. Its output was connected to the power supply, a Tennelec Model 901RM Dual Power Supply. The pulses from the preamplifier were fed directly to the pulse detecting device. For

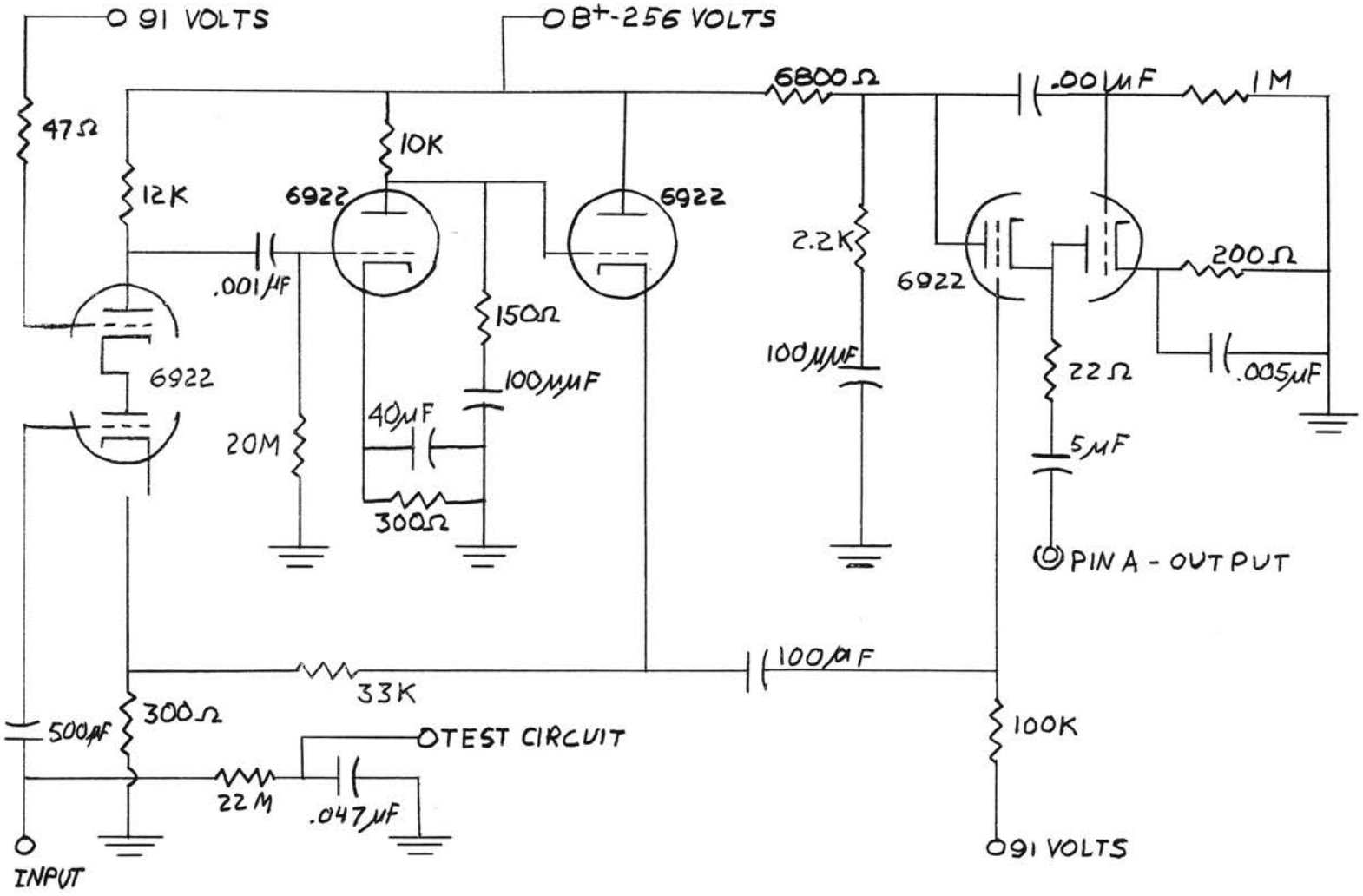


Figure 6. Preamplifier

testing purposes or trial runs this was sometimes an oscilloscope or a Berkeley scaler. In the actual measurements, however, this device was a 512-channel pulse analyzer-computer, Nuclear Data ND-130, which was equipped with its own power supply and oscilloscope.

The pulse analyzer further amplified the pulses and effectively sorted them as to pulse height. The circuit of each channel selected all pulses having a certain range of sizes and counted them. For an unsimplified, more complete description of a pulse height analyzer, see reference (38).

The analyzer was designed so that the channel number was a linear function of pulse size. It was equipped to record live time (the total time less the dead time, which is the time consumed in receiving individual pulses). Thus all the data needed to determine the activities for various alpha-particle energies could be obtained. Data was read out by the analyzer visually on its oscilloscope as a plot of the logarithm of number of counts versus channel number and by reading out the data automatically channel-by-channel which recorded it on paper.

# CHAPTER III

## EXPERIMENTAL METHODS

The first type of measurement to be discussed will be the measurement of the half-life of bismuth-215. The initial approach was to extract bismuth directly from an actinium solution from which thorium and radium had been separated. Such a solution was used in order to minimize the amount of bismuth-211 to be extracted, since 0.3 per cent of bismuth-211 beta-decays into polonium-211, an alpha-emitter with an energy of 7.44 MeV which is nearly equal to the energy of polonium-215 alpha-particles.

Bismuth-215 sources were made in the following manner. The separation of thorium and actinium was performed as described by Giessing (6). These separations were both TTA (thenoyltrifluoroacetone) extractions. The details will not be described here. Bismuth was extracted from this solution with dithizone at a pH of 2. The bismuth was returned to the aqueous phase by shaking with one normal nitric acid. The acid was neutralized back to a pH of 2 and again bismuth was extracted using dithizone. The dithizone was filtered (to remove any tiny droplets of the water phase still remaining) onto a planchet which was above a hot plate. This planchet was flamed after the liquid had been

evaporated from it. The planchet was then mounted on the source plate of the ionization chamber, the chamber was closed and flushed several times, and a series of runs was begun.

This approach had only limited success, largely because the bismuth activities obtained were much smaller than the amounts attainable theoretically (the actinium alpha-activity of the solution multiplied by the branching ratios of francium-223 and astatine-219 and by the percentage of the solution used in the source.) These low bismuth activities cuased poor statistics and greater relative error due to chamber background and due especially to bismuth-211 being fed by impurity traces of the main branch of the actinium series.

Greater success was obtained by using an astatine estraction. Astatine was extracted with chloroform from an acidic actinium solution from which the thorium and radium had been removed. The rest of the procedure was the same, except forty second runs were used sometimes instead of one or two minute runs. Runs were continued for one hour or more.

The bismuth-215 activity (and also the polonium-215 activity) should have grown from zero at the time of the extraction with an initial slope equal to the negative of the initial slope of the decay of astatine-219. As soon as a significant amount of bismuth was present, its decay lessened this slope and soon the bismuth decay predominated. Since the time until the peak bismuth activity is reached is

only about six minutes, the time between the separation and the first run must be extremely short (less than two minutes) to obtain the initial slope and the half-life of astatine-219. Since this speed could not be obtained with the type of equipment already built, it was decided to drop any ideas about measuring the astatine-219 half-life and to concentrate on the bismuth-215 half-life as originally planned.

For details concerning the determination of the relative alpha-activities under different peaks of an alpha spectra, see Giessing (6). Usually about six channels were used for the 7.4 MeV peak. For each series of runs there was determined the number of channels to be used for the bismuth-211 double peak in order to obtain a percentage of the total bismuth-211 counts equal to the percentage of the total 7.4 Mev counts obtained in the channels selected for that peak. See Table II for an example of the calculations for an astatine source. 0.3 per cent of the bismuth-211 activity was subtracted from the 7.4 MeV activity and corrections were made for general background, if necessary, which was obtained by graphically determining the non-decaying portion of the activity, and for double pulses, if significant. The inaccuracies in these corrections were always large enough that the half-life was determined by making a semi-logarithm plot of polonium-215 activity versus time and drawing a straight line that best fitted the data. Of course, the polonium activities used were divided by the live time of their respective runs. A range of error for each point of

TABLE II

SAMPLE CALCULATIONS OF AN ASTATINE SOURCE
(See Figure 6 for the alpha-spectra for some of the runs. The calculations are based on such spectra.)

| Run | 1 | 4 | 7 | 12 |
|---|---|---|---|---|
| Bi-211 Channels | 37-51 | 38-52 | 38-52 | 38-52 |
| Bi-211 Gross | 221962 | 180024 | 11005 | 4847 |
| Bi-211 Background | 50/ch x 17ch = 850 | 43/ch x 17ch = 731 | 8/ch x 17ch = 136 | 2/ch x 17ch = 34 |
| Net Bi-211 x .003 = Po-211 | 221112 x .003 = 663.3 | 179293 x .003 = 537.9 | 10869 x .003 = 32.6 | 4813 x .003 = 14.4 |
| Polonium Channels | 62-72 | 62-72 | 64-74 | 64-74 |
| Polonium Gross | 920 | 1033 | 254 | 56 |
| Polonium Background | 20/ch x 11ch = 220 | 4.5/ch x 11ch = 49.5 | 0.2/ch x 11ch = 2.2 | 0 |
| Net Po-215 (Gross-Bg-Po-211) | 920-220-663.3 = 36.7 | 1033-49.5-5329 = 445.6 | 254-2.2-32.6 = 219.2 | 56-0-14.4 = 41.6 |
| Live Time (min.) | 0.6827 | 1.718 | 1.954 | 1.964 |
| Po-215 CPM (Net/L.T.) | 53.8 | 260 | 112 | 21.2 |
| Po-211 Error | 1.5 | 1.3 | 0.4 | 0.2 |
| Po Gross Error | 30.3 | 32.1 | 15.9 | 7.5 |

TABLE II (CONTINUED)

| Run | 1 | 4 | 7 | 12 |
|---|---|---|---|---|
| Po Bg Error | 20.0 | 8.0 | 1.0 | 0 |
| Square of Total Error | $2 \neq 919 \neq 400 = 36^2$ | $2 \neq 1033 \neq 64 = 33^2$ | $0.2 \neq 254 \neq 1 = 16^2$ | $0 \neq 56 \neq 0 = 7.5^2$ |
| Error, CPM | 53 | 19.4 | 8.0 | 3.8 |

the graph was calculated using estimates for the errors due to each correction and using the statistical error, the square root of the gross total of counts. The error for each activity was found by taking the square root of the sum of the squares of the individual errors. Then the error in the slope was determined graphically by constructing the straight lines with the maximum and minimum slopes and which passed through most of the line segments representing the ranges of error for individual runs. The half-life and error could then be calculated using

$$\mathcal{T} = 0.6931/\lambda \ ,$$

where $\lambda$, the decay constant of bismuth-215 was the slope of the semilogarithmic plot.

The determination of the half-life of bismuth-211 involved the same dithizone extraction procedure as described earlier. However, the extraction was made from a radium "waste" solution, obtained when radium-223 was separated from actinium (6), so that their would be at most negligible amounts of francium. The rest of the method was the same as that for bismuth-215 with only the following differences. The channels to be used for bismuth-211 could be chosen without reference to the polonium peaks. The high activities used resulted in large numbers of double pulses, so that double pulse corrections became very significant since the number of double pulses increases as the square of the activity. After the net bismuth-211 activity was calculated

for each of a series of runs as well as the average time of the run (see Table III for sample calculations), the slope of the resulting semilogarithm curve was calculated using an International Business Machines Model 650 data processing machine with a linear regression program which minimized the sum of the squares of the deviations from a straight line. The data points were weighed equally, but only points representing runs containing at least 10000 counts were used so that the maximum statistical error was one per cent. This program also yielded an error calculation based on the deviation of points from a straight line. The error as calculated by the method used for bismuth-215 was similar in magnitude. The greatest of the two errors was adopted. Finally the slope was used to calculate the half-life in the same manner as for bismuth-215.

The other measurement made was that of the branching ratio of bismuth-211. Some bismuth-211 half-life runs were used for this purpose but the best results were obtained from lead-211 sources.

The radium "waste" solution was used again. From this solution lead and bismuth were extracted with dithizone at a pH of 8. The dithizone was shook with 0.01 normal nitric acid, taking the lead back to the aqueous phase again. The dithizone was discarded and the aqueous phase was neutralized to a pH of 8. The lead was then extracted with dithizone. this dithizone was filtered onto a planchet and evaporated. The planchet was flamed. After a short wait while the

TABLE III

SAMPLE CALCULATIONS FOR A BISMUTH-211 SOURCE
(See Figure 7 for spectra for some of these runs. The calculations are based on such spectra.)

| Run | 1 | 4 | 6 | 12 |
|---|---|---|---|---|
| Time of run, min. | 0 | 3.000 | 7.167 | 19.333 |
| Live time, min. | 0.8756 | 0.9445 | 0.9747 | 0.9866 |
| Bi-211 channels | 41-48 | 41-48 | 41-48 | 41-48 |
| Bi-211 gross total<br>and gross cpm | 87159<br>99542 | 35397<br>37477 | 9480<br>9726 | 267<br>271 |
| Background correction<br>(see spectra) | 94 | 92 | 90 | 83 |
| Net Bi-211 CPM<br>(gross-bg.) | 99448 | 37385 | 9637 | 188 |
| Gross error<br>(square root of gross) | 295 | 188 | 97.4 | 16.3 |
| Gross error, CPM | 337 | 199 | 99.9 | 16.6 |
| Bg-error<br>(estimated) | 30 | 30 | 30 | 30 |
| Square of total<br>error | $337^2+30^2$<br>$\approx 339^2$ | $199^2+30^2$<br>$\approx 40700 \approx 202^2$ | $99.9^2+30^2$<br>$10880 \approx 104^2$ | $16.6^2+30^2$<br>$1176 \approx 34.2^2$ |
| Total error, CPM | 339 | 202 | 104 | 34.2 |

bismuth grew back in from the lead, runs were begun. These runs were longer, two to ten minutes in duration, and were continued for several hours, since the activity decayed with a 36.1 minute half-life. The choice of channels for the bismuth-211 double peak and for the polonium-211 peak were chosen as they were in bismuth-215 half-life calculations (for a typical spectrum, see Figure 8). Then, after the gross activities for these peaks had been determined for a number of runs and the corrections were made for double pulses (these sources were highly radioactive), graphical determinations of the amounts of activity which did not decay with a 36.1 minute half-life were made for each peak and these amounts were subtracted from their respective peaks as shown in Figure 11. (This correction was usually less than one per cent for early runs.) The alpha-activities remaining could have been due only to bismuth-211 and polonium-211.

The runs used were those runs which were sufficiently radioactive (over 100 counts in the polonium peaks) to have good statistical accuracy and whose activities were not so great that double pulse corrections were larger than five per cent for polonium. As a check against systematic error, the polonium activity for each run was divided by its bismuth activity. If these quotients were reasonably consistent, the sum of the polonium-211 activities for all the selected runs was divided by the sum of the bismuth-211 activities for the same runs to yield the branching ratio of

bismuth-211. The total relative error was calculated as the square root of the sums of the squares of the relative errors, which are: the polonium-211 statistical error, one divided by the square root of the total polonium counts; the bismuth-211 statistical error (usually negligible).

TABLE IV

SAMPLE CALCULATION FOR THE BRANCHING RATIO
OF BISMUTH-211 FROM A LEAD-211 SOURCE
(The spectra were identical in shape to Figure 7.)

| Run | 1 | 4 | 7 |
|---|---|---|---|
| Time of run, min. | 0 | 38 | 75 |
| Live time, min. | 10.0 | 10.0 | 10.0 |
| Bi-211 channels | 30-39 | 30-39 | 29-38 |
| Bi-211 gross total | 178267 | 92047 | 46604 |
| Background correction (from spectra) | 300 | 300 | 300 |
| Net Bi-211 counts | 177967 | 91747 | 46304 |
| Po-211 channels | 44-51 | 44-51 | 43-50 |
| Po-211 gross total | 520 | 265 | 137 |
| Background correction (from spectra) | 15 | 15 | 15 |
| Net Po-211 counts | 505 | 250 | 122 |

Totals From 9 Runs

| | | | |
|---|---|---|---|
| Bi-211 counts | | | 774964 |
| Po-211 counts | | | 2141 |
| B.R. = $\frac{\text{Po-211 counts}}{\text{Bi-211 counts}}$ | | | 0.2763 |
| Po-211 statistical error | $2141^{0.5}/2141$ | or | 22% |
| Non-decaying Po-211 subtraction error | 90/2141 | or | 4.2% |
| Non-decaying Bi-211 subtraction error | 2700/775000 | or | 0.35% |
| Sum of squares of all error | 22.4 | or | $4.74^2$ |
| 4.74% of 0.2763 (total error) | | | 0.0131 |

# CHAPTER IV

## DATA AND RESULTS

The alpha spectra depicted in the figures on the next two pages are examples of the spectra obtained for the half-life determination of bismuth-215 (Figure 7) and for the determination of the half-life of bismuth-211 (Figure 8). Figure 7 is also similar in shape to the alpha spectra from the lead sources used in determining the bismuth-211 branching ratio except for the lower activities. The peak channels used are indicated. The decays are shown by superimposing an early spectra and a later spectra on each graph.

Figures 9, 10, and 11 are typical decay curves of bismuth-215 from an astatine source, of bismuth-211 from a bismuth-211 source, and of bismuth-211 from a lead-211 source, respectively. Figure 9 shows the growth of bismuth from astatine and the bismuth decay which follows. Straight lines indicate the curves obtained after corrections were made for background radiation.

Numerous attempts to measure the half-life of bismuth-215 half-life yielded the following values from three successes:

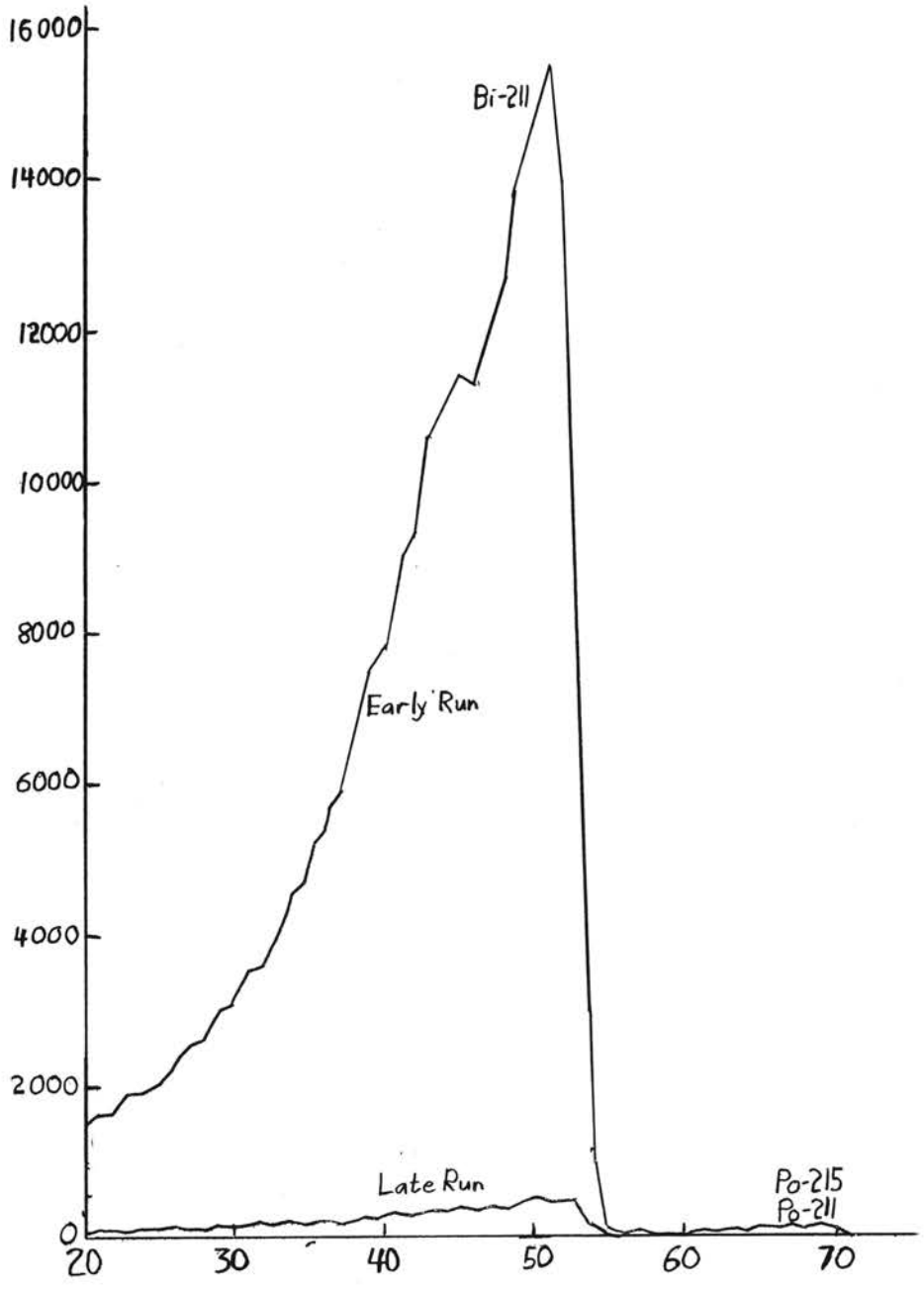


Figure 7. Alpha Spectra from an Astatine Source

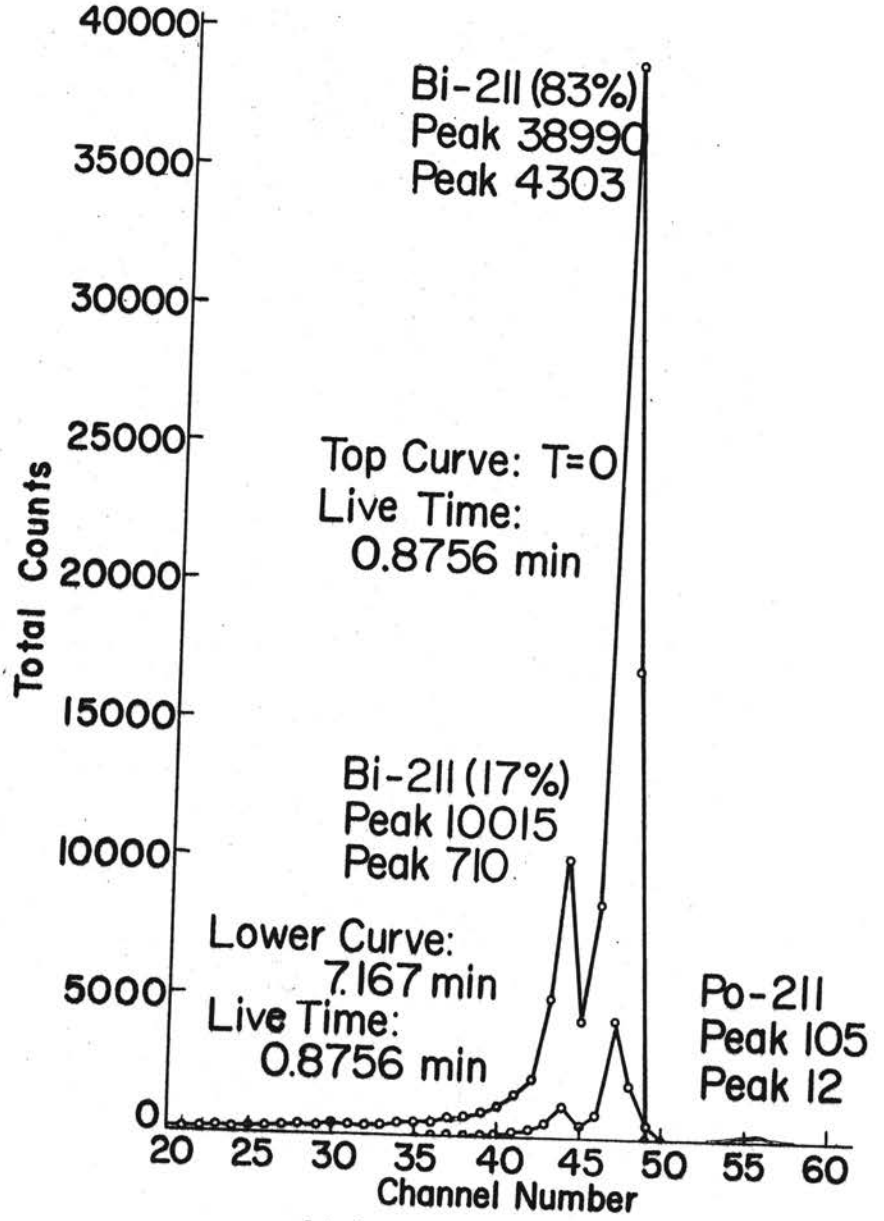


Figure 8. Alpha Spectra, Bi-211 Source

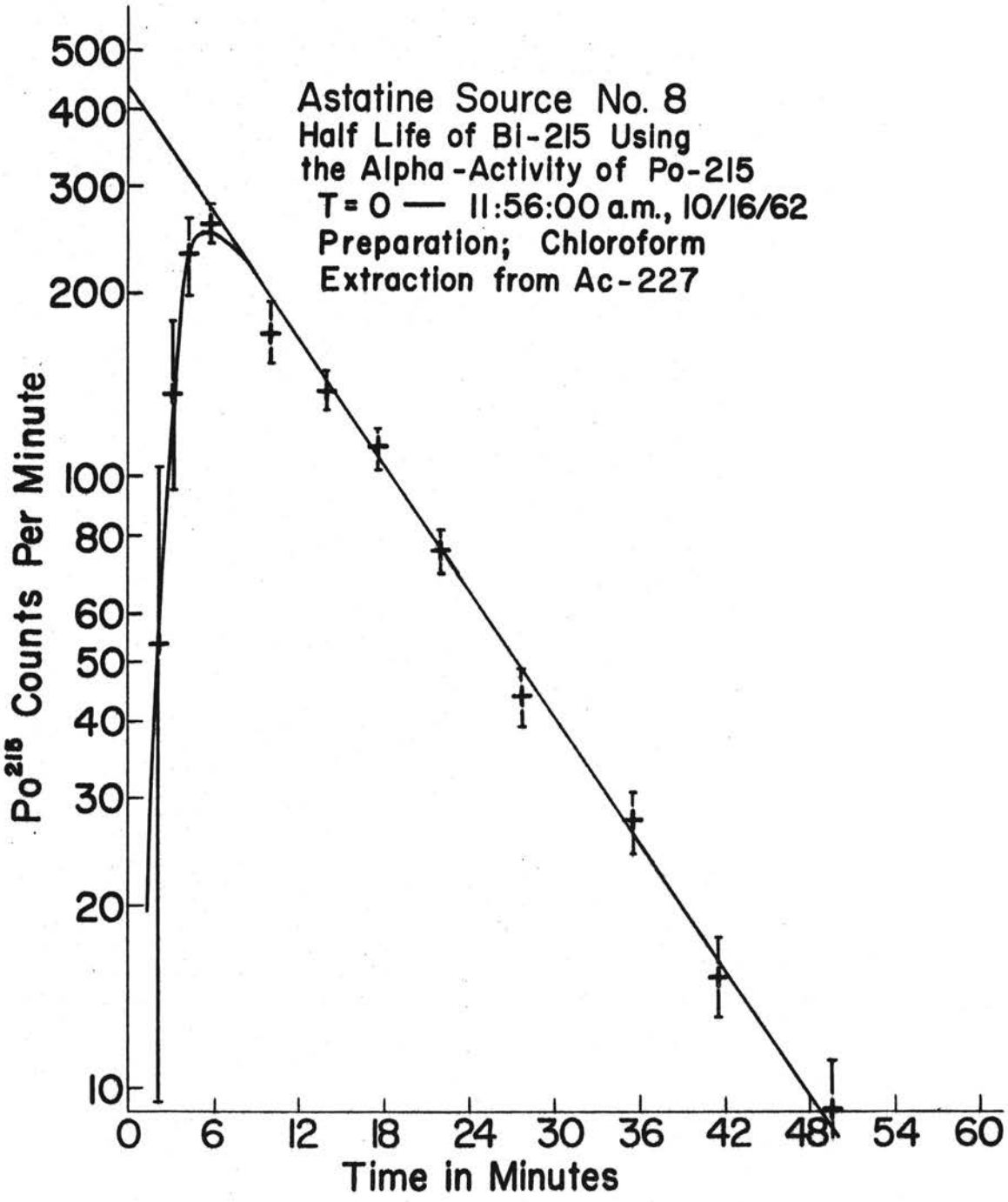


Figure 9. An Astatine Source

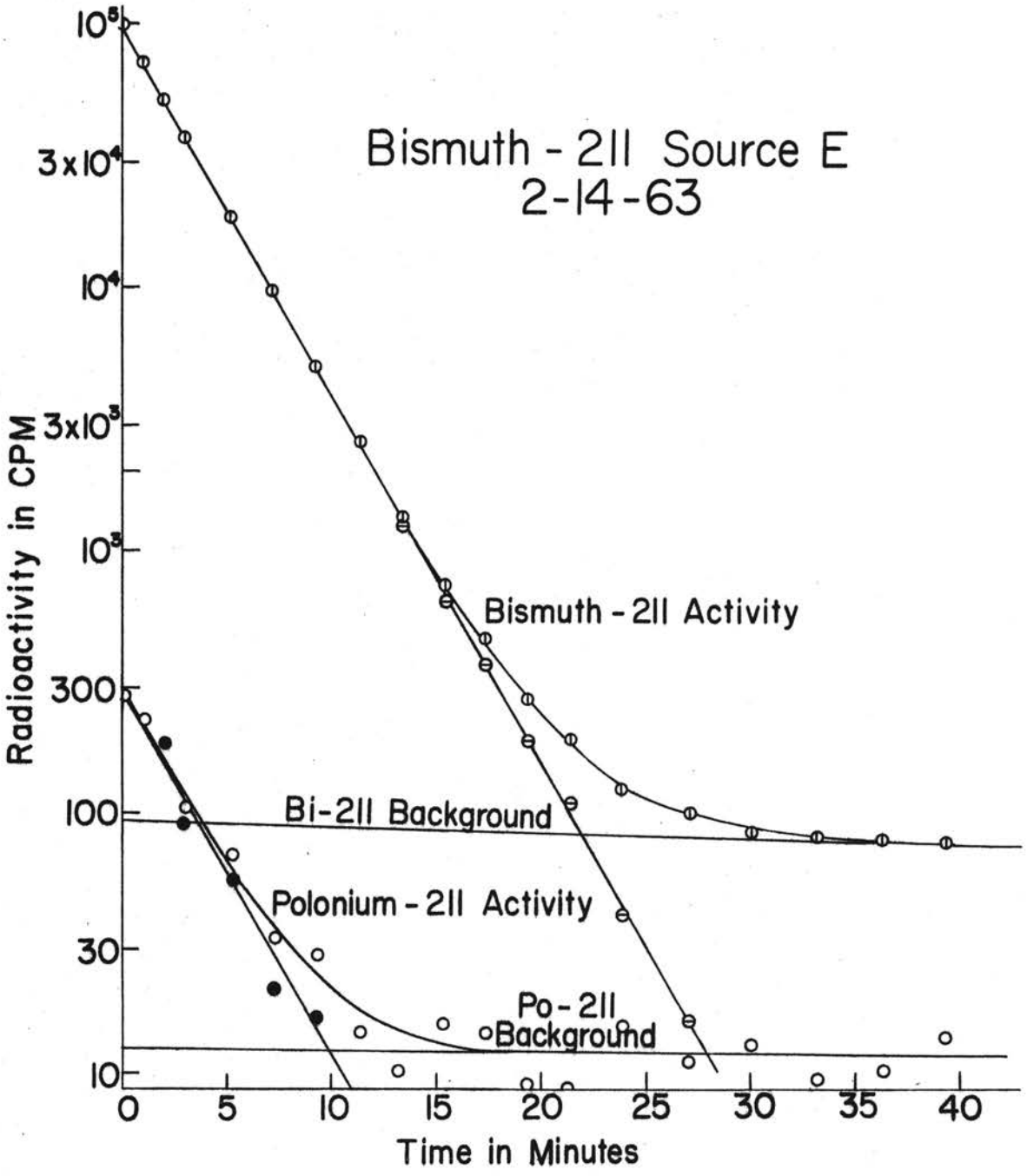


Figure 10. A Bismuth-211 Source

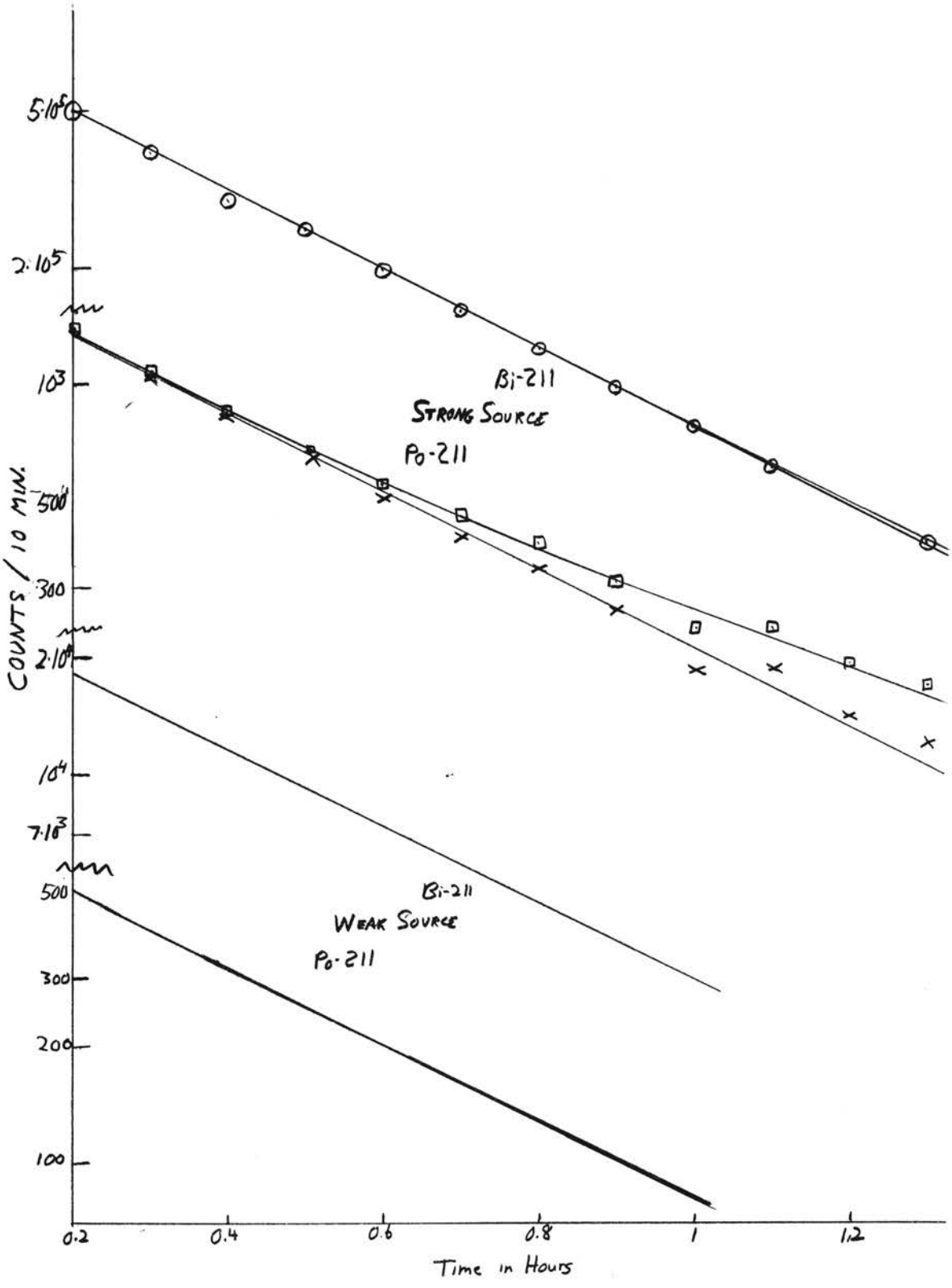


Figure 11. Decay Curves for Lead Sources.

$8.1 \pm 1.5$ min.
$8.05 \pm 0.8$ min.
$8.62 \pm 0.7$ min.

Combining these results the value for the half-life of bismuth-215 is

$8.3 \pm 0.7$ minutes

The average (8.34) was obtained using a weighing inversely proportional to the square of the corresponding errors.

The three best bismuth-211 half-life measurements were recalculated using a data processing machine, yielding the following values:

$2.123 \pm 0.011$ minutes
$2.143 \pm 0.020$ minutes
$2.131 \pm 0.020$ minutes

Combining these results the half-life of bismuth-211 was determined to be:

$2.13_0 \pm 0.01_5$ minutes

Four successful measurements were made of the branching ratio of bismuth-211. The values obtained were:

$0.284 \pm 0.013$ per cent
$0.266 \pm 0.015$ per cent
$0.276 \pm 0.013$ per cent
$0.270 \pm 0.010$ per cent

The final result for the branching ratio of bismuth-211 was:

$0.27_4 \pm 0.01$ per cent

## CHAPTER V

## DISCUSSION AND CONCLUSION

The results are summarized in the following table.

TABLE V

RESULTS

| Measurement | Result | Previous Result | Investigation and Date |
|---|---|---|---|
| Bi-215 Half-life | 8.3 ± 0.7 min. | 8 ± 2 min. | Hyde and Ghiorso, 1953 (32) |
| Bi-211 Half-life | $2.13_0 \pm 0.01_5$ min. | 2.16 min. | Spies, 1954 (24) |
| Bi-211 Branching Ratio | $0.27_4 \pm 0.01\%$ | 0.32% | International Radium Standards Commission, 1931 (23) |

The first result compares favorably with the only previous published result. This measurement was still a major disappointment, however. The use of sources prepared with a dithizone extraction still seems to be the most promising way to accurately determine the bismuth-215 half-life, but more knowledge of the chemistry of dithizone and bismuth will be needed. Another possibility would be to attempt to improve the method of Hyde and Ghiorso (32).

The value of 2.13 minutes for the half-life of bismuth-211 is somewhat less than previous results. Although some

systematic error might be suspected, the use of bismuth-211 alpha-decay was made to measure the half-life of lead-211 and the accepted value of 36.1 minutes was obtained.

The branching ratio of bismuth-211, 0.27 per cent, is much lower than the value of 0.32 per cent reported in 1931 by the International Radium Standards Commission. In view of the date of the previous measurement the difference in values is not surprising.

No new fine structure was observed for bismuth-211 or for either polonium-211 or polonium-215.

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# VITA

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