Journal of the Korean Physical Society, Vol. 65, No. 4, August 2014, pp. 532∼540

Use of a GM Counter to Measure the Half-life of Ba-137m Generated by Using an Isotope Generator

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(Received 2 January 2014, in final form 26 February 2014)

A Cs-137/Ba-137m isotope generator is used to demonstrate the properties of radioactive decay. In this experiment, we investigate and verify the random behavior of radioactive decay and determine the half-life of a radioactive isotope. The half-life of a radioisotope is measured in this experiment. The purpose of this experiment is to determine the half-life of Ba-137m by using several methods and to determine the percent error for each determination. Ba-137m decays by gamma emission (662 keV) with a half-life of 2.6 minutes to the stable Ba-137 element. During elution, Ba-137m is selectively "milked" from the generator, leaving behind the Cs-137 parent. Each generator is supplied with 250 mL of an eluting solution (0.9% NaCl in 0.04M HCl). A Geiger counter interfaced with a computer is used to acquire and record the activity at set time intervals. The half-life of the radioactive isotope Ba-137m is determined by measuring the activity of a sample as it decays. The half-life of Ba-137m, which has been extracted from the radioisotope Cs-137, is detected by using AktivLab. The theoretical half-life of Ba-137m is approximately 2.56 minutes, and the result from the experiment is 2.6 minutes. In summary, a radioisotope generator containing Cs-137 produces Ba-137m, which is extracted in a solution. The Ba-137m has a half-life of about 2.6 minutes as measured during this research.

PACS numbers: 87.58.Sp, 87.66.-a, 87.66.Jj, 87.53.Bn
Keywords: Halflife, Radioisotope, Cs-137, Ba-137m
DOI: 10.3938/jkps.65.532

I. INTRODUCTION

In this experiment, we will study the radioactive decay law by analyzing data for the purpose of measuring the disintegration of a short-lived radioisotope as a function of time. We will also investigate the statistical nature of radioactive decay. Radioactive elements emit alpha, beta or gamma radiation to become a new element or a new isotope of the same element. Alpha particles, α, are helium nuclei that have a charge of +2 and a mass number of 4. Beta minus particles, β, are electrons with a charge of -1 and a mass number of 0. Gamma rays, γ, are electromagnetic radiation similar to X-radiation and, thus, have 0 mass and 0 charge. An 'm' in an isotope's

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name, such as Ba-137m means that the element is in a metastable state and decays by emission. Examples of nuclear equations for each type of decay mode are given below. Notice that the mass and charge balances; the mass (and charge) on the left must be the same as the mass (and charge) on the right. The identity of the new element that is formed is found from the charge of its nucleus, which is the atomic number of the element. The rate of radio-nuclear decay is measured in terms of its half-life, $t_{1/2}$, the length of time necessary for one half of a given mass of the radioactive isotope to decay. We will measure $t_{1/2}$ for Ba-137m in this experiment.

Experiments on secular equilibrium in physical systems for the introductory modern physics laboratory have taken various forms. One of the earliest has the disadvantage of requiring neutron-activation techniques [1]. Some authors [2, 3] have described electronic simulation methods, and others [4, 5] have proposed fluid flow experiments. The present work is based on isotope-generator techniques [6–8] that have been used in the undergraduate laboratory for many years.

The objectives of this experiment are (1) to study radioactive decay, (2) to learn the concept of nuclear activity, (3) to learn the concept of a radioactive half-life and how to measure it, and (4) to measure the radioactive half-life of an isotope of barium. This experiment will show the exponential behavior of radioactive decay.

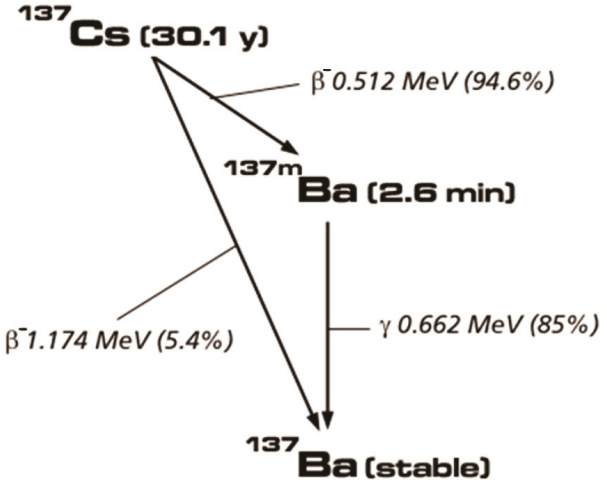

Fig. 1. Diagram of the radioactive decay of Cs-137 to Ba-137. In this process, 94.6% of the nuclei are found to decay to the 662-keV excited isomeric state Ba-137m. Ba-137m then decays to the ground state of Ba-137 with the emission of a 662-keV gamma ray.

II. MATERIALS AND METHODS

In this experiment a Geiger-Mueller (G-M) tube with a scaler/timer will be used to measure the radioactive half-life of an isotope of barium, Ba-137m, a metastable state of barium before it decays to its ground state. The activity of Ba-137m is measured as a function of time by detecting the gamma rays that are emitted, and the half-life is computed from the decay rate constant.

The activity of the sample cannot be measured instantaneously, but instead a number of radioactive decays are detected and counted over a series of short time-intervals. This number can be shown to change exponentially with the same decay constant as the activity and, therefore, is equivalent to measuring the instantaneous activity. Also, the number of detected particles is a fraction of the total number of decays because the radiation is emitted from the source in all directions, and the detector only intercepts a small portion of these directions. In other words, the detector only sees a small fraction of the total solid angle. The detector also has an efficiency for counting particles that enter it that is less than 100%. The efficiency is usually a constant for a given setup and a given set of measurements, but the measurements still have the characteristic exponential relationship with the same decay constant. For high count rates, detectors in general, but especially GM tubes, have difficulty counting particles that occur nearly simultaneously. This problem, referred to as the dead time, can be avoided by keeping the counting rates small enough that the time between counts is much larger than the time resolution of the detector and counter. With these additional factors taken into consideration, the detected number of particles is still proportional to the activity of the sample and has the same decay constant.

Background radiation is a common source of error in radioactive decay counting, and although small, this error can lead to a small inaccuracy in the measurement of the half-life. The background radiation comes from many naturally-occurring materials that emit radiation and from cosmic rays entering our upper atmosphere from space. Background radiation is a constant addition to the detected activity and produces an offset count that doesn't fit the exponential decay of the source material. Fortunately, the measurements can be easily corrected to compensate for this offset. A background measurement is made by removing all other sources to be measured from the vicinity of the detector and then counting for a long time to establish an accurate measurement of the background. Then, the background is simply subtracted from each of the measurements made with the sources present.

1. Materials

Radioactive Ba-137m can be extracted from a Cs-137 sample (Fig. 1). The relative activity of Ba-137m is then measured by counting emitted gamma rays with a GM counter that is interfaced with a computer. By the time 30 minutes have passed, essentially no radioactive Ba137m remains, and it may be disposed of safely

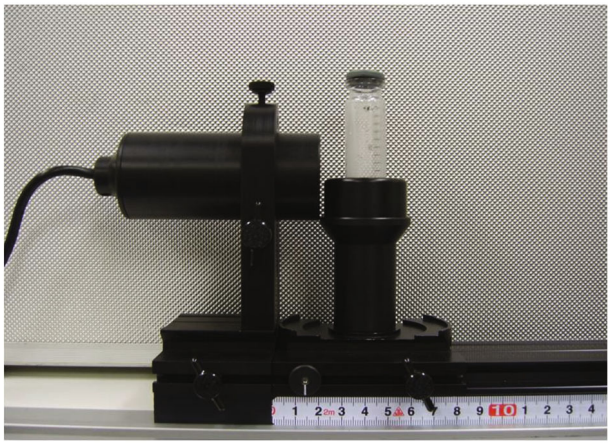

Fig. 2. (Color online) Photo of the Geiger-Mueller tube.

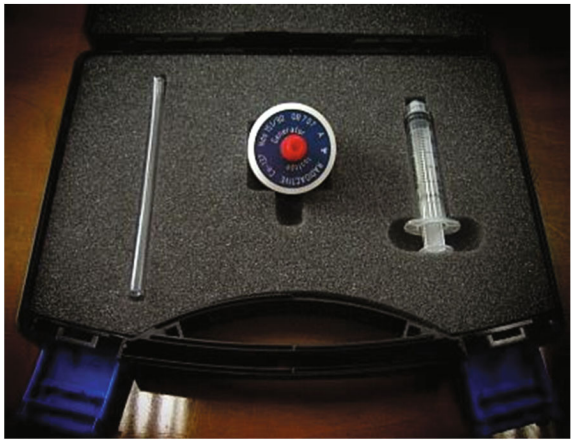

Fig. 3. (Color online) RI milking generator.

down the drain. The range of internal deviations for the instruments used in this study has been accurately maintained within ±0.05%. The calibration and the correction of the radiation equipment were completed in August 2013 by the Korea Advanced Institute of Science and Technology. The decay scheme is shown in Figs. 2 and 3 and consists of (1) a nucleus scaler/timer, (2) a GM tube with stand and source holder, (3) a cesium-137/barium-137m isotope-generator, (4) a planchet, (5) a source holder tray, (6) a Pasco Science Workshop 750 data interface, (7) Pasco Science Workshop software, (8) Excel software, and (9) a computer system. The performance of the Geiger counter depends on the highvoltage supply, which is pre-set for this experiment. Normally, an experiment would be run to determine the operating voltage, but that process has been eliminated for this experiment to concentrate on the study of the measurement of the half-life. Unless otherwise indicated, the high voltage for the counter is set at 900 volts.

The instructor will make the Ba-137m source for each experimenter when ready. Counting should start as soon as possible after the sample is made. After the run, the planchet with the used Ba-137m source material should be placed in a baking dish in a sink to be washed. After each Ba-137m source has been washed, about 5.0 minutes is required for the Ba-137m to build back to 3/4 strength. Thus, the instructor should rotate through several isotope-generators for each class. Remember to wipe up any spills and to wash yourself thoroughly if any of the source material should come in contact with your skin.

Normal safety and wastedisposal safety precautions are taken; that is, safety glasses and gloves should be worn throughout this experiment. The amount of radioactive material used is extremely small. The Cs-137/Ba-137m isotope generator is exempt from federal or state licensing and requires no special handling, storage or disposal. The Ba-137m isotope decays to practically zero activity within 15 minutes. Exempt liquid products such as this can be discarded in the sink. Gloves and paper towels may be thrown into normal trash containers.

2. Measuring the Background Radiation

To measure the background, collect data for approximately 100 seconds. Record values on your data sheet, take an average of the readings, and round to the nearest count. This value will be subtracted from future readings (Fig. 3).

Run a battery check on the Geiger counter. Connect the powered up Geiger counter to the LabPro and the LabPro to a computer. Set Logger Pro to take ten-second readings for the experiment's duration of 25 minutes. Explain to your instructor how you are going to perform the next steps before you carry them out. Then, perform those steps carefully [1]:

Place a planchet on the sample tray. Dip the end of a syringe into the solution and pull the plunger to fill the syringe. Remove the caps from each end of the isotope-generator. Insert the syringe firmly into the entry hole on the top of the generator. While holding the generator vertically, force approximately seven drops of solution through the generator onto the planchet. Do not reverse the flow of the eluting solution through the generator into the syringe. Immediately place the planchet sample next to the Geiger counter and begin counting. Remove the syringe from the generator and replace the caps. After 30 minutes, the syringe eluting solution and planchet solution are safe to rinse down the drain. Save your data in an Excel spreadsheet.

3. Determination of the Half-life of Ba-137m

Obtain a Cs-137/Ba-137m mini-generator, plastic syringe with tubing, and a small metal disc included in the isotope-generator kit. Obtain about 2 mL of eluent

Table 1. Measurement of the background.

Trial	Series									
	1	2	3	4	5	6	7	8	9	10
1	17	11	12	7	7	6	9	8	5	7
2	10	13	15	15	14	13	6	12	9	14
3	11	12	6	8	9	14	10	12	8	9
4	6	9	9	12	9	12	8	13	8	5
5	12	16	10	10	8	10	12	5	10	10
6	15	11	9	9	10	11	10	10	13	13
7	16	9	10	14	13	11	10	9	8	8
8	9	10	6	8	11	8	17	14	11	15
9	7	10	11	16	10	9	12	7	12	7
10	14	11	6	6	14	13	13	11	14	11
Mean	11.7	11.2	9.4	10.5	10.5	10.7	10.7	10.1	9.8	9.9
AVG	10.5 ± 0.7									

Note: The numbers are expressed as counts per second.

Table 2. Background data.

Series	Average
1	56.8
2	60.9
3	59.9
4	57.8
5	55.6
mean	58.2 ± 2.4

Note: The numbers are expressed as counts per second.

solution in a small test tube (1 mL ≈ 20 drops). This solution should be 0.9% NaCl and 0.04M HCl. It is not radioactive. Push the CLEAR button on the screen to clear any data from the data array (Fig. 3). Attach the tubing to the plastic syringe. Draw about 1 to 2 mL of eluent up into the syringe through the tubing. Then, remove the tubing from the syringe. The tubing is useful when the syringe is not long enough to reach into the container of eluting solution. Hold the mini-generator over the small metal disc. Remove the end caps from the top and the bottom of the mini-generator, and attach the syringe to the top opening of the mini-generator (see accompanying figure). Carefully press the syringe to elute about 6 drops from the bottom opening of the mini-generator onto the metal disc. These drops contain the Ba-137m. Note the time (the position of the second hand) as soon as the 6 drops have been eluted. Return the caps to the mini-generator as soon as possible. If any of this eluted liquid spills, wipe up the spill immediately with a paper towel and dispose of it in the dry waste jar in the waste hood. Wait one minute from the time you eluted the 6-drop sample, and then start taking 10-second counts. Continue to take 10-second counts immediately after each other for a total of 7 minutes. You should have 42 10-second counts.

The data array on the screen only shows about 10 trials, but all of your trials are contained in that array. To view more than the first 10 trials, use the array index (the first 10 values are index numbers 0-9). With 42 counts, you should have indices 0 through 41 in your data array. When all trials are done, upload the data to Excel. Be sure to save the data. Clean up by rinsing the metal disc and placing the liquid into the liquid radioactive waste bottle in the waste hood. Do not put liquid wastes into the jar for Thorium clean-up waste. The plastic syringe and tubing can be rinsed in the sink.

4. Half-life of Ba-137m

Wait until your instructor is in position to add the Ba-137 to the planchette. Press the collect button. A message window opens. Select discard (bottom left). Your instructor will deposit a small amount (5-10 drops) of the Ba-137m onto your planchette. Data will automatically be plotted on the chart. (Note that the data are sampled every ten seconds.) Collect the data for 600 seconds.

When collection is done, stop the count by pressing the red collect button (Fig. 3). Go to the data table (top menu), and record time (seconds) and radiation (counts) onto your data/results table. Subtract the background reading from this value; record the result in the corrected column of the data table.

To determine the half-life by using your tabulated data, take all cpm values needed from the corrected cpm column in your table. Find the largest cpm reading from

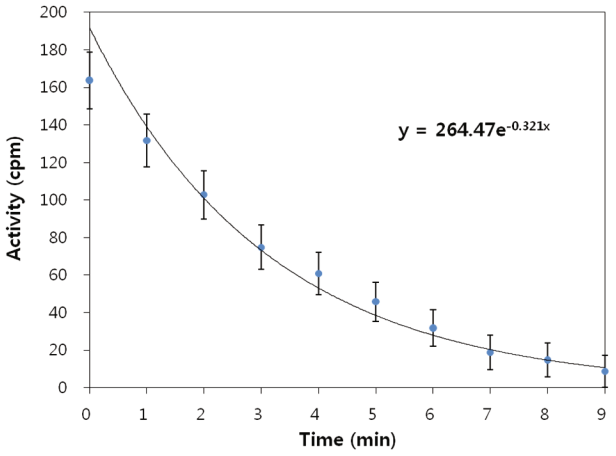

Fig. 4. (Color online) Typical results for the decay of barium following separation, as obtained by using a Geiger counter.

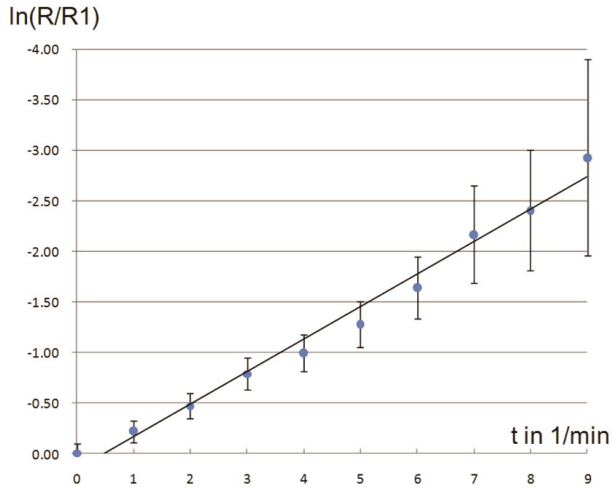

Fig. 5. (Color online) Linear decay curve of Ba-137m.

the data table. Record the time in seconds for that reading. Divide this cpm reading by 2. Find the corrected cpm value from your data that is closest to this reading. Record the corresponding time. In most cases you will have to estimate the time. Find the time difference between the largest cpm reading and the cpm/2 reading. This is the half-life of Ba-137m in seconds.

To determine the half-life by using a plot of corrected counts vs. time (s), plot the counts on the y axis and time on the x-axis. Make sure that the corrected radiation count points are drawn as vertical error bars to reflect the uncertainty in the readings. To find the half-life, select a reading and its corresponding time, then, select the half-reading and its time. The difference in times is the half-life. We conducted our study using Ba137m because of its short half-life, and we assumed that only a slight deviation between the theoretical and the experimental half-lives would be clearly seen in the measurements.

III. RESULTS

The background radiation was measured 10 times at intervals of 10 seconds. The mean value of all counts for natural radioactivity was confirmed to be 10.5 (Table 1). Table 2 lists the results of the background measurements. The measurements were conducted for a total of 5 series with 1 series consisting of 10 measurements at intervals of 60 seconds. The mean value for each series was calculated before calculating the mean value for the 5 series. According to the calculation results, the mean value was 58.2 with a standard deviation of 2.4.

Table 3 lists the measurement results for radioactivity from Ba-137m for the experiment that reflected the theory most precisely. The net counting rate and the standard error were plotted to calculate the precise value of the half-life of Ba-137m. Figures 4 and 5 show graphs for the numbers in Table 3. As shown in the figures, the number was halved every 2.6 minutes. In Fig. 4, the net counting rate for 0 minute is 173.8, and half of this number is 86.9, which corresponds to a time of approximately 2.7 minutes, which is the half-life. In Fig. 4, the data are plotted on a semi-log scale, and the result is a straight line with a slope of -0.32. Using the half-life formula half-life = 0.693/decay constant (λ), where the decay constant is the negative of the slope of the straight line, we obtain a half-life of $0.693/0.32 = 2.2$ min.

IV. DISCUSSION

The Cs-137/Ba-137m isotope generator is designed to demonstrate the properties of radioactive decay. Based on the original Union Carbide design, it offers exceptional performance combined with ease of use and safe operation. This product is exempt from USNRC and State licensing and requires no special handling, storage or disposal. A small quantity (< 10 μCi.) of radioactive Cs-137 is bound on a special ionexchange medium. The Cs-137 parent isotope beta decays with a 30.17year half-life to produce Ba-137m, which in turn decays with a 2.55min halflife, generating a 661.6keV gammaray.

This gamma ray may be readily detected using a GM or scintillation radiation detector. An eluting solution is used to selectively extract the Ba-137 isotope from the exchange medium, leaving the parent Cs-137 isotope in place to regenerate more Ba-137. Equilibrium is reestablished in less than 1 hour. Approximately 30 minutes after elution, the residual activity of the Ba-137 solution has decayed to less than 1/1000 of its original activity, making it safe for normal disposal. When used with the eluting solution supplied, bleed through of the Cs-137 parent isotope is less 50 Bq/mL. If correct chemical stability is to be maintained, using only the correct eluting

Table 3. Experimental data for determining the half-life.

Time (s)	Count (N_i)	Net counting rate (min^{-1}) (curve)	Standard deviation	Net counting rate (min^{-1}) (linear)	Standard error (linear)
0	232.0	173.8	15.4	0.0	0.1
1	193.0	134.8	14.1	−0.2	0.1
2	159.0	100.8	12.8	−0.5	0.1
3	138.0	79.8	12.0	−0.8	0.2
4	127.0	68.8	11.5	−1.0	0.2
5	113.0	54.8	10.9	−1.3	0.2
6	100.0	41.8	10.3	−1.6	0.3
7	89.0	30.8	9.7	−2.2	0.5
8	77.0	18.8	9.1	−2.4	0.6
9	70.0	11.8	8.7	−2.9	1.0

Table 4. Half-life values for the four methods used in this work and from the literature. Each value is the weighted average of the results of five measurements. The range of Chi-square values is given for these five measurements.

Detector	Method	Half-life	Range of Chi-square[a]
Geiger counter	Decay	2.577 ± 0.009	0.97 − 1.14
	Growth	2.568 ± 0.042	0.85 − 1.10
NaI spectrometer	Decay	2.576 ± 0.006	0.95 − 1.03
	Growth	2.550 ± 0.009	0.98 − 1.05
Literature value[b]		2.552 ± 0.001	

a. Range of Chi-square probability: 0.10 − 0.97. Fourteen of the twenty Chi-square probabilities fall in the range 0.30 − 0.70.
b. National Nuclear Data Center, Brookhaven National laboratory, Upton, New York11973, [http://www.nndc.bnl.gov/nndcscr/testwww/AR137BA.HTML]. This recommended value is the weighted average of four published measurements.

solution is important. Additional solution may be ordered as part ELSN or prepared by the user as 0.9% NaCl in 0.04M HCl. When making the solution, use distilled or DI water to avoid unwanted mineral contamination.

The isotope Cs-137 is unstable and decays by emitting an electron (a process also known as β^- decay) with a 5.4% probability of decaying to the ground state of Ba-137 and a 94.6% probability of decaying to an excited state Ba-137m, which is 662 keV above the ground state. This excited state is unusually longlived, lasting on the order of minutes as opposed to the nanoseconds or the picoseconds for typical excited states of nuclei. This decay process is represented in the energy diagram shown in Fig. 1. The half-life of metastable Ba-137 nuclei will be measured. These nuclei are products of the radioactive decay of Cs-137. The decay scheme is represented in the energy-level diagram shown.

The half-life of Cs-137 is 30 years. When Cs-137 decays, a neutron in this nucleus changes to a proton with the emission of a β particle. Most of the time, the daughter nucleus Ba-137 is created in the metastable Ba-137m state. The half-life of this state is 2.55 minutes, and it decays to the ground (lowest energy) state of Ba-137 by emitting a gamma ray with an energy of 662 keV. Only 6% of the time does the Cs-137 decay directly to the stable ground state of Ba-137. An isotope generator containing Cs-137 is used to produce the radioactive nuclei. When one drop of dilute HCl is passed through the generator, some Ba atoms go into solution and are removed from the generator. The instructor uses a circle of green felt moistened with this solution to measure the half-life of the Ba-137m nucleus.

The halflife of the isomeric state can be determined by measuring the activity with time, which follows

$$A = A_0 e^{-\lambda t}, \tag{1}$$

where A is the relative activity at time t, A_0 is the relative activity at time $t = 0$, and λ is the decay constant. Experimentally, the number of gamma rays, C, detected from the sample in a given time interval will be proportional to A, while the statistical nature of the decay causes an uncertainty in C that is given by $\sqrt{C}$. A physical system that satisfies the conditions for secular equilibrium is the Cesium-137/Barium-137 mixture.

Figure 1 show the decay scheme for this system.

The source material for Ba-137m is an isotope generator consisting of an exempt quantity of Cs-137. An exempt quantity is a quantity small enough that no license is required to purchase the material and, therefore, is deemed to be a minimal health hazard. The cesium atoms are in molecules of a cesium salt, CsCl, that have been adsorbed by small beads of a resin material. The Ba-137m atoms are a daughter product that results from the decay of Cs-137 according to the scheme shown in Fig. 1. As the Cs-137 atoms decay to the Ba-137m atoms, the Ba-137m atoms remain adsorbed on the surface of the resin, but because barium is in a different chemical form than the cesium was previously, it is more loosely bound to the resin and can be de-adsorbed with a weakly acidic salt solution containing HCl and NaCl. Small aliquots of the shortlived Ba-137m isotope can then be extracted from the resin by using this eluting solution. The cesium atoms have a half-life of 30 years and are always decaying and building up an equilibrium amount of Ba-137m. Ba-137m has a half-life of only 2.55 minutes (153 seconds) and quickly decays to its stable ground state by the emission of a 0.662 MeV gamma ray.

The Ba-137m is said to be selectively "milked" from the generator, which is sometimes referred to as a "cow." As the Ba-137m daughter product is washed out of the generator, the Cs-137 parent product is left behind to regenerate additional Ba-137m atoms. Regeneration of the Ba-137m occurs as the Cs-137 continues to decay, and equilibrium is re-established in less than an hour. Because Ba-137m has a short half-life, it only takes approximately 30 minutes after a sample is acquired for the residual activity to have decayed to less than onethousandth of its initial activity, thus making it safe for disposal. However, regardless of how safe this isotopic generator system is to work with, care should be taken to avoid spills and contact with your skin. Should a spill occur or contact with the skin be made, wipe off the excess liquid and wash thoroughly with soap and water [9, 10].

The reactions for the scheme shown in Fig. 1 are

$$^{137}_{55}Cs \rightarrow ^{137}_{56}Ba^{m} + ^{0}_{-1}e + \bar{\nu}, \tag{2}$$

$$^{137}_{55}Ba^{m} \rightarrow ^{137}_{56}Ba + \gamma, \tag{3}$$

and are governed by the decay equation

$$R_B = \frac{\lambda_B R_{A0}}{\lambda_B - \lambda_A}(e^{-\lambda_A t} - e^{-\lambda_B t}), \tag{4}$$

which for

$$T_A \gg T_B,\ \lambda_B \gg \lambda_A \ or\ T_{\frac{1}{2}}(B) \ll T_{\frac{1}{2}}(A) \tag{5}$$

is given by

$$R_B \approx \frac{\lambda_A R_{A0}}{\lambda_B}(1 - e^{-\lambda_B t}), \tag{6}$$

where R_{A0} is the initial activity of A, R_B is the activity of B, and $T_{1/2}$(A) and $T_{1/2}$(B) are the halflifes of A and B, respectively. For $t \gg T_{\frac{1}{2}}$(B), $\frac{R_B}{R_{A0}} = \frac{\lambda_A}{\lambda_B}$, and B is in secular equilibrium with A. In our case, A is Cs-137 and B is Ba-137m.

AktivLab contains a Cs-137/Ba-137m isotope generator. The radionuclide Cs-137 has a halflife of 30.25 years and decays via a metastable state (Ba-137m, halflife 2.6 min) to a stable isotope of barium (Ba-137). This decay scheme is shown in Fig. 1. The generator is used in two ways in AktivLab: first, it is used to illustrate the principle of a radionuclide generator, in which a shortlived radionuclide is obtained from a longerlived parent; second, the generator is used as a source of gamma radiation. The generator has a nominal activity of 370 kBq of Cs-137. The eluting solution and the instructions on elution are included in AktivLab. The eluting solution can also be ordered separately.

Radioactive decay follows firstorder kinetics. This means that the rate of decay is proportional only to the amount of unstable isotope present. We can write this as [11,12]

$$\frac{dy}{dt} = ky\ (where\ k < 0), \tag{7}$$

where y = the number of atoms of the unstable isotope at time t. We can solve this differential equation and get

$$y = y_0 e^{kt}. \tag{8}$$

The decay constant k ("relative rate of decay") depends on the particular isotope and nothing else. A representation for the decay of a nucleus is

$$\text{Parent nucleus} \rightarrow \text{daughter nucleus} + \text{radiation particle}. \tag{9}$$

The radioactive isotope ^{137m}Ba can be produced in a container called an isogenerator, or "nuclear cow", by the decay of ^{137}Cs. The decay process looks like

$$^{137}Cs \rightarrow {}^{137m}Ba + \beta^{-} \rightarrow {}^{137}Ba + \gamma. \tag{10}$$

The cesium decays to metastable barium with the emission of a beta-minus particle (β^-, an electron). The halflife for that reaction is about 30 years. The metastable barium has a short half-life; it loses excess energy as low-energy gamma radiation (γ) to form stable ^{137}Ba.

Both types of barium, stable and unstable, are produced inside the cow from the decaying cesium. They are separated from the cesium and flushed out by "milking the cow", that is, by passing a dilute solution of hydrochloric acid and NaCl through the cow. Barium reacts with the acid to form soluble barium chloride, and the solution is drained out. The cesium does not react, being held by an ion-exchange medium inside the cow.

A Geiger counter, located next to a small beaker with the barium solution, will be used to measure the "activity

rate" R(number of clicks in each time interval). Each γ from a decaying nucleus picked up by the Geiger counter produces a click representing the decay of one barium nucleus. Then the number of clicks recorded per minute has something to do with the number of nuclei that have decayed in that minute.

The nuclear decay process described above can be detected by observing the 2.6 minute half-life associated with the decay of Ba-137m. The Cs-137/Ba-137m generator can produce small quantities of the shortlived Ba-137m isotope. The Ba-137m sample is produced by gently forcing an eluting solution (0.9% NaCl) through an exchange medium containing the parent Cs-137 isotope. During elution, the Ba-137m is selectively "milked" from the generator, leaving behind the Cs-137 parent. Regeneration of the Ba-137m occurs as the Cs-137 continues to decay, re-establishing equilibrium in less than 1 hour. Each generator contains 10 μCi of Cs-137, which represents an exempt quantity, making if free from specific state and federal licensing requirements. Approximately 30 minutes after elution, the residual activity of the Ba-137m solution has decayed to less than 1/1000 of its original activity, making it safe for normal disposal. A Geiger-Müller tube can detect the gammaray emission associated with the decay of the Ba-137m nuclei, and the computer will record the number of events per minute. The instructor will provide a few drops of an HCl-NaCl solution containing the eluted Ba-137m. Radioactive decay is described by the equation

$$N(t) = N_0 e^{-\lambda t}, \tag{11}$$

where N(t) is the number of radioactive nuclei remaining at time t, N is the initial number at t = 0, and λ is the decay constant. The activity, A, or the number of disintegrations per unit time given in Eq. (1) is related to the number of decaying nuclei N by A = λN. The mean life, τ, is equal to the inverse of the decay constant and is related to the half-life, $T_{1/2}$, by the equation $T_{1/2} = \tau\ln(2) = 0.693\tau = 0.693/\lambda$. In this experiment, you will measure $T_{1/2}$ and compare your experimental value with the known half-life of 2.6 minutes.

The nature of radioactive decay is determined by the fundamental fact that the probability per unit time that a radioactive nucleus will undergo decay is equal to some positive constant called the decay constant. The value of this constant depends on the type of decay and on certain properties of the nucleus undergoing decay (the parent nucleus), as well as on the nucleus that remains after the decay has taken place (the daughter nucleus). From this fundamental relation, it follows that for a sample containing N radioactive nuclei at time t, the number decaying per unit time is N and the number dN that decay in time dt is Ndt. Because the nuclei that decay in time dt represent a decrease in the number of parent nuclei present in the sample, one can write the change in N as dN = − Ndt. Integrating this expression from t = 0 to some later time t yields the radioactive decay law (Eq. 11), where No is the number of parent nuclei present at t = 0.

$$R = \frac{-dN}{dt} = N_0 e^{-\lambda t} = R_0 e^{-\lambda} \tag{12}$$

where Ro is the initial activity. The unit of activity is the Becquerel, defined as 1 disintegration/sec. Also used is the Curie (Ci), where 1 Ci = 3.7 × 10^{10} Becquerels. When the natural logarithm of activity is plotted versus time, a straight line results.

The decay rate of a radioactive isotope is normally characterized by its half-life, $t_{1/2}$, which is defined as the time required for one-half of a given number of nuclei to decay. Equivalently, $t_{1/2}$ is the time interval during which the activity of a radioactive sample decreases by a factor of two:

$$\frac{N}{N_0} = \frac{1}{2} = e^{-\lambda t_{\frac{1}{2}}} = \ln\frac{1}{2} = 0.693 = -\lambda t_{\frac{1}{2}} \tag{13}$$

The experiment was conducted using an AktivLab radiation dosimeter with a view to measuring the half-life of a radioactive isotope and to appling the measurement results in clinical practice. Although the experiment was conducted based on an AktivLab laboratory note, there were many limitations on the measurements of the background due to the location and other factors. The natural radiation was difficult to measure at a low dose. Furthermore, performing an active measurement was very difficult because the experiment was conducted several times for simple natural radiation. Ba-137m was used at the radioisotope because it has a short half-life. Therefore, measuring its half-life is case, as is obtaining such light sources compared to other light sources [3].

If the half-life of a radioactive isotope is considered in clinical practice, the radiation dose that still remains in the body system can be calculated. Owing to such calculations, delays in examinations can be prevented because the examination time can be kept precise. In addition, the time for replacing therapeutic radionuclides such as Co-60 and Cs-137, which is conducive to the maintenance and management of performance, can be determined; furthermore, radioactive isotopes are being used in an increasing number of fields. Radioactive isotopes are used not only for diagnosis but also for treatment. In addition, radioactive isotopes are used to help perform surgery, treat diseases to help patients relieve their fears, and obtain a greater effect by creating a synergistic effect from performing surgery and conducting treatment simultaneously. A wider variety of isotopes are gradually being used, which leads to an expansion of the treatment scope using isotopes.

In this experiment, many trial and error processes existed, which brought the aforementioned results. The results suggest the following: In the initial experiment, the conclusion was not in accordance with theory. The reasons are that the authors were not familiar with the experimental process and were faced with many limitations

on the location for measurement of background. Nevertheless, the authors conducted the experiment many times and obtained a value that was as close as possible to the value in theory. In addition, a more precise experiment can be conducted if the following factors are taken into consideration:

First, natural radiation should be excluded as much as possible to conduct a precise measurement of the half-life of a radioactive isotope. Therefore, the experiment should be conducted in a space shielded with a lead wall or in a vacuum. This experiment was conducted both above and below ground in a school building. A comparison of the results in the two places confirmed that natural radiation was lower below ground than above ground.

Second, recording the time for the radioactive equilibrium of the isotope is important. After Ba-137m was eluted from CS-137, it took approximately 20 30 minutes until the equilibrium state was restored. Therefore, the elution needs to take place at a time when the Ba-137m concentration is highest [4]. A lack of compliance with such an amount of time can lead to Ba-137m with impurities, which means erroneous results.

Third, determining if the experiment was successful was difficult due to insufficient data and targets for comparison. In addition, the experimental place was unsuitable for special equipment or experiment. On the other hand, the authors obtained a value of 2.6 minutes, which was close to the 2.56 minutes determined based on half-life theory, which indicates that the experiment result was in accordance with theory. In this research, application of the Ba137m radioisotope to the diagnostic area also implies that the radiation exposure of patients administrated a radioisotope can be reduced, as can the time for the imaging process with the isotope, due to its short half-life. That shorttime requirement for diagnosis is another advantage of the clinical application a radioactive isotope.

V. CONCLUSION

This work demonstrates that an isotope generator may be used to demonstrate secular equilibrium in threelevel radioactive decay. The experiment lends itself to the use of several types of nuclear counting systems. Significant results can be achieved with inexpensive Geiger counter units. The study of secular equilibrium enhances and extends the use of the isotope generator. Two samples can be produced with a single elution. The experiment lends itself to data analysis, non-linear curve fitting and goodness of fit studies.

ACKNOWLEDGMENTS

This work was supported by the Nuclear Safety Research Program through the Korea Radiation Safety Foundation (KORSAFe) and the Nuclear Safety and Security Commission (NSSC), Republic of Korea (Grant No. 1305033).

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