EXPERIMENT 22

Measurements in Radiation Biology and Nuclear Medicine Training

EQUIPMENT NEEDED FROM EG&G ORTEC

Bin and Power Supply
905-3 2- by 2-in. NaI(Tl) Crystal and Phototube
266 Photomultiplier Tube Base
556 High Voltage Power Supply
113 Scintillation Preamplifier
ACE-2K MCA System including suitable IBM PC (other EG&G ORTEC MCAs may be used)
575A Amplifier
719 Timer
875 Counter
903 End-Window Geiger Tube
906 GM Inverter
Two pieces of PbPI-3 (see Appendix)
Source Kit SK-1G (see Appendix)
Ten pieces of PnPI-1 (see Appendix)
25 μCi ^{131}I as sodium iodide for thyroid uptake test
100 μCi ^{32}P as sodium phosphate for plant studies
One large white laboratory rat (~300 g)
Ten young bean plants with 7 or 8 leaves on each plant
Miscellaneous radiobiological supplies such as syringes, pipettes, rubber gloves, filter paper, dissecting trays, animal boards, lead storage containers
ORC-22 Cable Set
Oscilloscope

Introduction

In radiation biology and nuclear medicine, as well as in radiation chemistry, it is often convenient to use radioisotope tracers. A radioisotope tracer is, generally, a chemical compound that contains at least one radioactive component. The amount of the radioactive chemical component that is present in the tracer should be related to the complexity and type of experiment that is to be performed. In terms of the atom, its chemical and biological behavior is determined for the most part by its orbiting electrons. Two isotopes, for example ^{12}C and ^{14}C, will enter into identical chemical reactions in a biological system because their electronic structure is the same. However, ^{14}C is radioactive, and so it can be traced as it goes through its complex biochemical reactions in the animal or plant system that is being studied.

Therefore, when it is necessary to study the behavior of a particular chemical or molecular configuration, a sample can be synthesized with a small fraction of one of the elements replaced by a radioactive element in an amount and with a half-life that is compatible with the necessary measurement for the experiment. The compound is then assayed for its specific activity and is introduced into the system being studied.

For most radiobiological and medical studies, isotopes that decay by betas or gammas are used. Gammas are quite penetrating and so, where applicable, gamma-emitting isotopes can be used in "in vivo" studies. This means, for example, an isotope is injected into a patient or an animal and a gamma counter is used to follow the rate and/or concentration of the isotope as a function of time. Normally, the activity rate of the tracers is so small that an animal or patient is not even aware of the fact that measurements are being made. On the other hand, particularly for beta-emitting isotopes, it is frequently necessary to perform "in vitro" measurements where a sample must be physically removed from a plant or animal and measured externally with a counter.

Table 22.1 lists the most commonly used radioisotopes for these studies.

In this series of experiments, we will study some geometrical considerations in radiobiological and medical applications and perform some simple plant and animal experiments with radioactive tracers.

Table 22.1. The Most Common Isotopes Used in Radiation Biology.

Isotope	Type of Radiation	Half-Life
^{3}H	beta	12.3 years
^{14}C	beta	5570 years
^{51}Cr	gamma	27.8 days
^{99m}Tc	gamma	6.0 hours
^{131}I	gamma	8.07 days
^{198}Au	gamma	2.7 days

EXPERIMENT 22.1

Geometrical Considerations in Radiobiological and Medical Experiments

Purpose

For many bio-tracer experiments the measurements can be made in vivo. For example, in Experiment 22.2 we will study the uptake of ^{131}I in the thyroid. For these measurements the major source of radioactivity is the thyroid gland, which is surrounded by flesh and tissue. There are also bones close to the gland, and they can cause Compton scattering and hence distort the measured spectra.

In this experiment, we will study some of the effects that are observed when there is material between the source and the detector or surrounding the source.

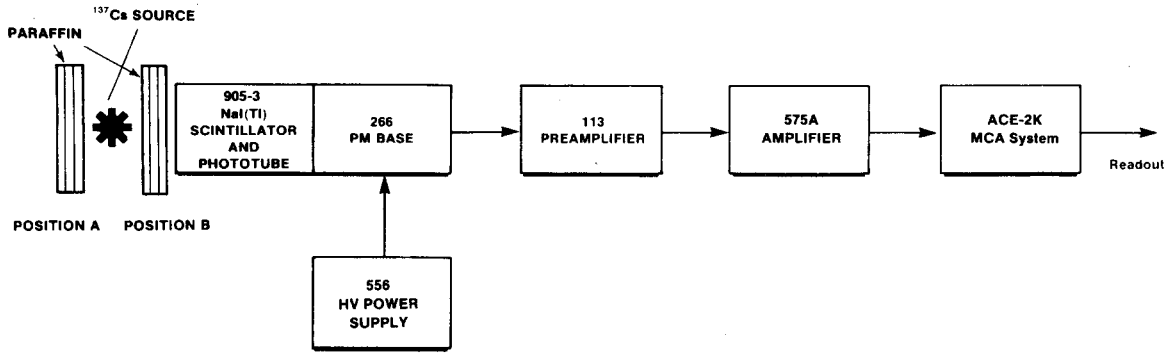

Fig. 22.1. Gamma-Spectra Measurements with Material Surrounding the Source.

Procedure

1. Set up the electronics and physical arrangement as shown in Fig. 22.1. Be sure to allow room between the source and the detector for inserting five pieces of 1/2-in. thick paraffin during the experiment.

2. Adjust the gain of the amplifier and the high voltage for the phototube so that the photopeak for ^{137}Cs (from the Source Kit) is near channel 300; this procedure was outlined in Experiment 3.

3. Store a spectrum in the MCA for a period of time long enough to obtain 1000 counts at the top of the photopeak. Figure 22.2 (the solid line) shows a typical ^{137}Cs spectrum. Read the data out of the MCA. Clear the analyzer to zero.

4. Place the first piece of paraffin in position A, Fig. 22.1, and store a spectrum for the same amount of time that was used in step **2**. Read the data out of the analyzer and clear to zero.

5. Repeat step **4** with two, three, four, and then five pieces of paraffin in position A, Fig. 22.1.

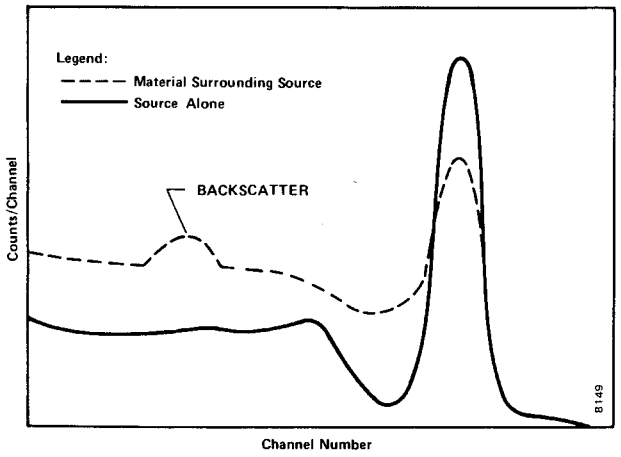

Fig. 22.2. NaI(Tl) Spectra with ^{137}Cs Source Alone and with Paraffin Surrounding the Source.

6. Without disturbing the paraffin in position A, place the first piece of paraffin in position B. Count for the same time period used in steps **2** and **3**. Read the data out of the analyzer and clear to zero.

7. Repeat step **6** for two, three, four, and five pieces of paraffin in position B.

EXERCISES

a. Plot on semilog paper the spectra recorded in step **2**, with no paraffin. On the same graph paper, use different symbols and plot only the backscatter portion of the rest of the spectra measured in steps **2** and **3**. Note that the photopeak remains the same for all spectra taken with paraffin in position A, but the backscatter is enhanced as the thickness of paraffin is increased.

b. On another piece of semilog paper, plot again the spectrum taken with the source and with five pieces of paraffin in position A. On the same sheet, plot the spectrum that was taken with all five pieces of paraffin in position B. The broken line in Fig. 22.2 is a typical ^{137}Cs spectrum that was measured in this manner.

c. Integrate the counts in the photopeaks of the spectra measured in steps **6** and **7** and make a linear plot of counts vs paraffin thickness.

Summary

In vivo biological and medical measurements almost always result in distorted scintillation measurements because materials between the source and the detector can be expected to eliminate some counts from the peak and also enhance the Compton scattering distribution. The distortion is produced by the photoelectric effect and Compton scattering in the material that surrounds the effective source in the biological sample that is being studied. However, by knowing the magnitude of these distortions, accurate biological measurements can still be made for most systems.

EXPERIMENT 22.2

^{131}I Uptake Studies in Rats

Purpose

A rather high percentage of the natural iodine in an animal's body is concentrated in the thyroid gland. If a solution of sodium iodide that is labeled with ^{131}I is injected into a rat, about 30% of it is accumulated quickly in the thyroid gland. Most of the remainder will be excreted as urine by the animal. A counter held over the thyroid will begin to register ^{131}I gammas almost immediately after injection of the animal. The purpose of this experiment is to study the concentration in the thyroid gland of the injected ^{131}I as a function of time. In vitro measurements will also be made to show the relative concentration of ^{131}I in other organs, compared to that in the thryoid.

Procedure

1. Pipette about 1 μCi of ^{131}I from your stock solution onto a counting card and dry it with a heat lamp. Cover the source with a thin piece of Mylar. This will be used as a calibration source.

2. Set up the electronics as shown in Fig. 22.1. Place the 1-μCi source card 2 cm from the detector.

3. Set the 456 High Voltage for the value that is recommended for the phototube in the 905-3 detector. Adjust the amplifier gain so that a spectrum similar to Fig. 22.3 is obtained. For this experiment, the 364-keV and 280-keV lines will be used (see Fig. 22.4 for the decay scheme of ^{131}I to ^{131}Xe). Readjust the amplifier gain to place the 364-keV gamma line in about channel 200. Store a spectrum in the MCA for a period of time long enough to have the peak height in the 364-keV line at ~1000 counts. Read the data out of the analyzer. Do not clear to zero.

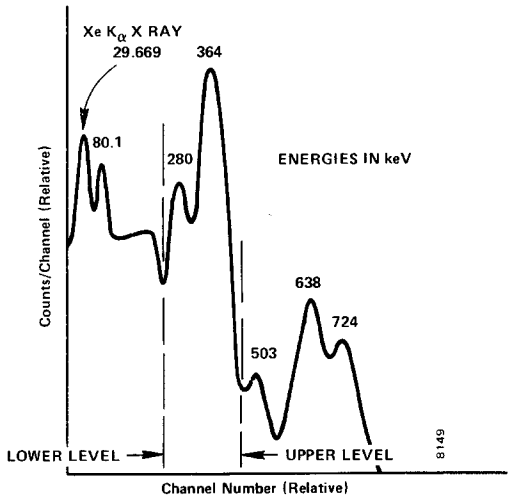

Fig. 22.3. Sodium Iodide Spectrum of ^{131}I Showing Major Lines and the ^{131}Xe X Rays.

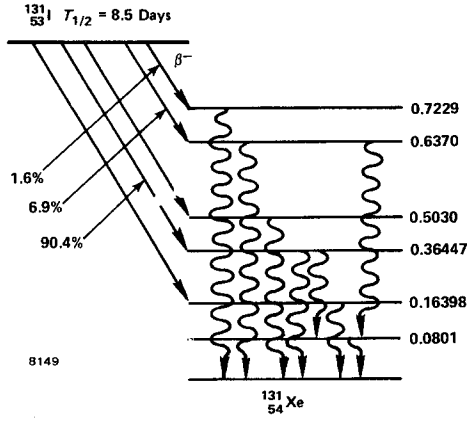

Fig. 22.4. Decay Scheme for ^{131}I Showing Major Gamma-Ray Energies.

4. Set the ROI of the MCA so that it brackets the 364- and 280-keV peaks (Fig. 22.3). You are now ready to do the ^{131}I uptake study with the rat.

5. Anesthetize the white rat carefully with ether. Fasten the rat to the dissecting tray on its back, using rubber bands to hold the legs to the tray.

6. Inject the animal intraperitoneally with about 5 μCi of the radioactive sodium iodide solution. Record the time of injection. From this point, it is necessary to keep the animal anesthetized only during counting intervals. Do not overanesthetize the animal.

7. Support a 1-in. lead sheet over the animal's body to shield all but the neck area from the detector. Place the detector 3 in. above the neck of the aminal, where the thyroid is located.

8. Set the preset time controls on the MCA for 80 seconds. Take spectra at 10-minute intervals, using 80 seconds for each accumulation. Read out the data and clear the analyzer after each counting period. Plot the number of counts as a function of time and continue to take counts until the counting rate has peaked and has fallen ~10% below the maximum.

9. Wait two hours after the above experiments have been completed and then sacrifice the animal with ether. Dissect it and remove the thyroid, kidney, liver, spleen, stomach, and heart. Dry the organs with blotting paper. Place them, one at a time, on counting planchets at a distance of 2 in. from the 905-3 crystal and count for 400 seconds. For each organ, determine the counts per minute per gram of organ.

10. Count the 1-μCi standard ^{131}I card with the same geometry as was used for the organs (400 seconds).

EXERCISES

a. From your plot of ^{131}I uptake as a function of time, determine the time required for maximum uptake for your animal.

b. Calculate the percentage of the original 5 μCi of ^{131}I that is found in each of the organs. This can be done by comparing the total count for an organ to five times the count obtained on the 1-μCi counting card since the injection was 5 μCi.

EXPERIMENT 22.3

Translocation of Radio-Phosphorus in Plants

The use of radioactive tracer techniques in agriculture and plant study has given us a rather accurate account of some of the basic physiological processes that occur during plant metabolism. The study of uptake of mineral elements by plants and their subsequent incorporation in plant tissues have also been advanced greatly by use of these tracer techniques. Measurements in the translocation of organic compounds elaborated during photosynthesis and respiration are now fairly well understood, at least partly because of radioactive tracer studies.

A plant, like any other organism, is not capable of distinguishing between different isotopes of the same element. It will therefore metabolize radioactive phosphorus exactly the same way it would the stable isotope of the element. For these studies, ^{32}P is an ideal isotope to use either in vivo or in vitro. It decays by pure beta emission directly to the ground state of ^{32}S. The half-life of ^{32}P is 14.3 days and its beta end-point energy is 1.707 MeV.

Purpose

To study the translocation of phosphorus in young bean plants by counting the 1.707-MeV betas from ^{32}P with a Geiger Mueller counting system.

Procedure

1. Young bean plants should be used for this experiment. The seeds should be germinated and grown in the proper nutrient until the young plants have 7 or 8 leaves before they are ready for the experiment. Remove the plants carefully from the soil in which they were grown and wash all soil from the roots. Place a group of 5 plants in each of two flasks so that the root systems and stems are accommodated in the flasks and the leaves are outside the flasks.

2. Mix 20 μCi of ^{32}P-labeled sodium phosphate with enough water to cover all of the plant roots in the flasks. Do not add the solution to the flasks until the counting system is ready for use.

3. Set up the electronics as shown in Fig. 22.5. Adjust the 556 High Voltage Power Supply to the level that is to be used for the 903 Geiger Tube and set the 719 Timer for 1-min. counting intervals. Test the system with a 1-μCi ^{32}P counting card (see Experiment 22.2, step **1**, for this procedure).

4. Position the 903 Geiger Tube ~1 cm from one of the large young plant leaves. Be sure that it is properly shielded from the solution that is added to the flasks to cover the roots at this time. Take 1-min. counts every 10 min. for ~3 h and record each count total.

5. After ~24 h, remove all plants from their radioactive solutions. Carefully wash the roots and prepare the plants for dissecting. From several of the plants that seem to have survived best, dissect roots, stems, and leaves, and keep the items separated.

6. Carefully weigh the roots and place them in a counting planchet. Use enough to cover an area of ~1 sq. in. on the planchet. Place the planchet 2 cm from the Geiger tube and take a 5-min. count. Repeat for other groups of roots. From these measurements determine the number of counts per minute per gram of roots.

7. Repeat step **5** for stems and then for leaves.

8. Place the 1-μCi standard ^{32}P counting card 2 cm from the Geiger tube window and determine the number of counts per minute for the standard.

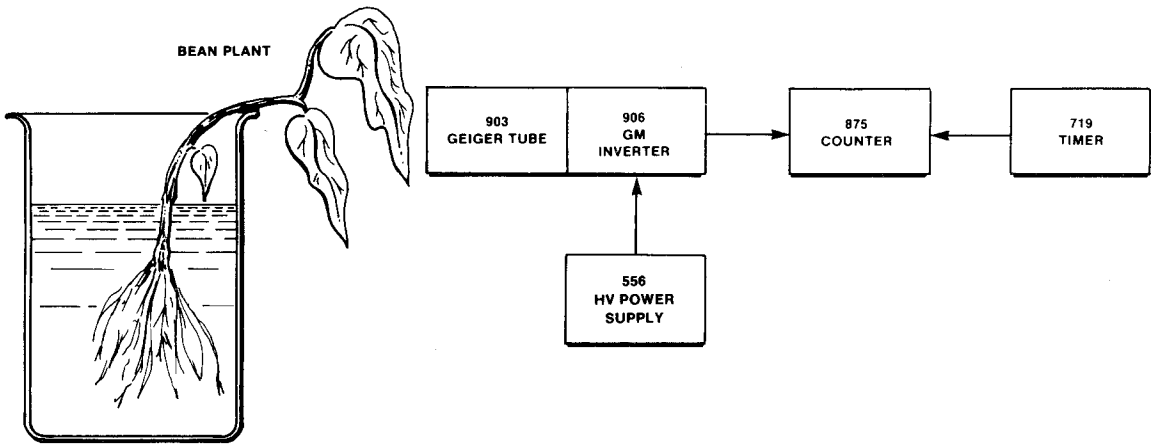

Fig. 22.5. Electronics for ^{32}P Studies in Plants.

EXERCISES

a. From the data that were taken in step **4**, make a plot of the activity found in the leaves vs time.

b. From the data that were taken in steps **5**, **6**, and **7**, determine the percentage of ^{32}P that was found in the roots of a given plant. This can be done by counting the roots of a plant and comparing the measurement to the 1-μCi counting card. Repeat the same comparison for stems and leaves by multiplying the counts per minute per gram by the total weight of the corresponding stems or leaves in one plant. From your measurements, summarize how long it takes phosphorus to be translocated to the leaves of the plant and how the phosphorus is distributed through the plant.

References

1. G. F. Knoll, *Radiation Detection and Measurement,* John F. Wiley and Sons, New York (1979).

2. A. C. Melissinos, *Experiments in Modern Physics,* Academic Press, New York (1966).

3. H. L. Andrews, *Radiation Biophysics,* Prentice-Hall, Inc., New Jersey (1974).

4. G. D. Chase and J. L. Rabinowitz, *Principles of Radioisotope Methodology,* 3rd Edition, Burgess Publishing Co., Minnesota (1967).

5. V. Arena, *Ionizing Radiation and Life,* The C. V. Mosby Co., Missouri (1971).

6. L. Cromwell *et al., Biomedical Instrumentation and Measurements,* Prentice-Hall, Inc., New Jersey (1973).

7. *Radiological Health Handbook,* U.S. Dept. of Health, Education, and Welfare, PHS Publication 2016. Available from National Technical Information Service, U.S. Dept. of Commerce, Virginia.

8. Alison P. Casarett, *Radiation Biology,* Prentice-Hall, Inc., New Jersey (1968).

9. Z. M. Bacq and P. Alexander, *Fundamentals of Radiobiology,* Pergamon Press, New York (1961).

10. S. Silver, *Radioactive Nuclides in Medicine and Biology,* Lea and Febiger Publishing Co., Pennsylvania (1968).