Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
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# Nuclear Medicine

Curriculum Unit 83.07.07
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## Introduction

This unit is designed to give the learner knowledge in the area of nuclear medicine, as well as improve math skills. This unit can be taught in part or can be ongoing throughout the school year.

Learners will become familiar with nuclear medicine through diagnostic imaging and its components. This will allow students to relate to real life situations. The activities in this unit will foster quantitative thinking in the learner, which will lead the learner to develop the interest, objectivity, attitudes and mathematical skills that are related in the area of nuclear medicine. It is my intent that the learners skills will grow and knowledge will increase with adequate use of this unit. The adequate use will enhance the required amount of application of a concept necessary to insure its future availability and in this way the learner will become literate to some degree within the area of nuclear medicine.

This unit will be taught to seventh and eighth grade middle school students. It can be taught to students on a high school level, especially those interested in the professional fields of nuclear medicine technology.

The middle school student is an entity in himself, with unpredictable reactions to problems and personal situations. The middle school student should begin to take a critical look at himself and to seek direction in his life and the establishment of his values. In this unit the student will explore nuclear medicine technology, its components and its usage in the medical profession. It is the intent of this unit to incorporate in nuclear medicine the concepts which will expose each student to an awareness and broad understanding of nuclear medicine. A wide range of exposure will allow a student to develop a career interest.

## *Nuclear Medicine*

In broad terms nuclear medicine is defined as the application of radionuclide techniques to the diagnosis and treatment of human disease. Nuclear medicine has been recognized as a medical specialty for the past decade or so.

Nuclear medicine was first used for the investigation of thyroid disease prior to the Second World War. During the past decade the field of nuclear medicine has expanded so rapidly and extensively that most practicing physicians trained prior to this growth are unaware of the numerous, valuable radioisotopic procedures now available to them.

Contemporary methods may be divided broadly into three groups. The largest division is diagnostic procedures, such as organ imaging, in which a radionuclide, in a suitable chemical form, is administered to a patient and the distribution of radioactivity in the body is determined by an external radiation detector. The second largest division of nuclear medicine utilizes radionuclide techniques to measure concentrations of hormones, antibodies, drugs, and other important substances in samples of blood or tissues. The third phase is therapy to treat disorder and restore the normal function of an organ.

In 1896, Henri Becquerel in France, discovered the use of radioactivity in Uranium. Radioactivity is defined as the property by which nuclei spontaneously decay or disintegrate by one or more discrete energy steps or transitions until a suitable stable state is reached.

Due to Becquerel's research, Marie and pierre Curie found that both uranium and thorium possessed this property of radioactivity, also that some uranium minerals are more radioactive than uranium itself. For this work Becquerel and the Curies were jointly awarded the Nobel prize for Physics in 1903.

Marie and Pierre Curie's work made an impact in the world of science with their discovery of one radioactive element radium, which changes into other elements. The Curie's research gave meaning to the inner world of the atom.

An element is a basic substance consisting of atoms which are chemically alike. For many years before the discovery of radium, scientists had believed that atoms were the smallest units of matter. The word atom comes from a greek word meaning indivisible.

However, today we understand that most of an atom is empty space with particles revolving around a tiny core, or nucleus. The nucleus contains particles called protons and neutrons tightly locked together. The particles which revolve around the nucleus are called electrons.

Many elements, of which radium is one, are naturally radioactive. This means that they are made up of atoms which are unstable, that is, the nuclei, or cores of these atoms are constantly disintegrating of their own accord. In the process of disintegration or decay, the atoms automatically give off particles and radiation, and change into lighter elements.

The major forms of radiation given off by radioactive elements are alpha particles, beta particles, and gamma rays.

The alpha particle is a helium nucleus consisting of two protons and two neutrons. This particle is the same as the helium atom with the exception that there are no orbital electrons. Because there are no negative charges to neutralize the positively charged nucleus, the alpha particle possesses an electric charge of plus two upon emission. Since the particle is without electrons, it will not be satisfied until it acquires two electrons, making it an electrically neutral helium atom.

One alpha particle is a combination of two protons and two neutrons. Alpha particles shoot out from the nuclei of splitting atoms, such as those of radium, at a speed of about 10,000 miles per second. Alpha particles can be stopped by a few sheets of paper and are unable to penetrate the unbroken skin, and they rarely cause any damage.

Beta particles are very light and have a continuous energy spectrum. The maximum energy available to the beta particle from nuclear decay is called the endpoint energy. The number of beta particles emitted with this maximum energy are few. Beta particles lose most of their energy ionizing atoms along their paths. Penetrating power of beta particles is high when compared to alpha particles.

Beta particles are electrons which shoot out from certain radioactive atoms at the speed upward from 100,000 miles a second, but they can be stopped by approximately an inch of wood. Beta particles can penetrate about one-third inch of human tissue and cause severe burns.

Gamma rays are a form of radiant energy, or radiation released from the nuclei of radioactive atoms when they disintegrate. Gamma rays are part of the electromagnetic wave spectrum as radio waves, visible light waves, and x-rays. Gamma rays are very much like x-rays, except that their wavelengths are shorter. Their penetrating power is enormous. The gamma rays of radium can be stopped by thick sheets of concrete or lead. They can pass right through the human body and therefore can be extremely dangerous because they are capable of destroying cell life.

When a radium atom gives off an alpha particle, it becomes a radon atom. Radon is a gas which has a very short life. Radon is the decay product of radium.

In recent years, the words nuclide and radionuclide have fallen into disfavor. These words have been replaced by the terms isotope and radioisotope. Nuclide refers to any nucleus plus its orbital electrons. Isotopes refer to two or more forms of the same element, in that they have the same number of protons and a different number of neutrons. A radioisotope will disintegrate at a constant rate, with the time required to reach fifty percent of the original number of atoms referred to as the physical half-life. A physical half-life is a factor considered when selecting a particular isotope for certain use.

Every radionuclide has a fixed half-life ranging from seconds to years. Those used in clinical nuclear medicine have half-lives in the range of minutes to days.

Radionuclides are measured in terms of the amount of radioactive atoms that disintegrate in one second. The terms employed are referred to as curies, named after Marie Curie. One curie of radioactive material means that it would have $3.7 \times 10^{10}$ disintegrations per second. Chart No. 1 on the following page defines the Curie and its sub-units.

## Chart No. 1

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| UNIT | SYMBOL | DISINTEGRATIONS PER SECOND | DISINTEGRATIONS PER MINUTE |
|---|---|---|---|
| Curie | Ci | $3.7 \times 10^{10}$ | $2.22 \times 10^{12}$ |
| Millicurie | mCi | $3.7 \times 10^{7}$ | $2.22 \times 10^{9}$ |
| Microcurie | uCi | $3.7 \times 10^{4}$ | $2.22 \times 10^{6}$ |
| Nanocurie | nCi | $3.7 \times 10^{1}$ | $2.22 \times 10^{3}$ |

## Chart No. 2

| SCANS | RADIOPHARMACEUTICALS | DOSAGE |
|---|---|---|
| Bone | Technetium—MDP | 15 mCi |
| Liver | Technetium—Sulfur Colloid | 6 mCi |
| Lung | Technetium—MAA | 4 mCi |
| Renal | Technetium—Glucoheptanate | 15 mCi |
| Thyroid | Technetium—Pertechnetate | 10 mCi |

## *Radiopharmaceuticals*

During the past decade or so nuclear medicine has advanced to become a specialty field all of its own. Highly technological radioisotopic detection devices and improved radiopharmaceuticals are the major reasons. Anyone interested in nuclear medicine for clinical practice should acquaint himself with radiopharmaceuticals and instrumentation.

The composition of a radiopharmaceutical; how they are obtained, their characteristics, and how radiopharmaceuticals are used to obtain information are some of the principles involved in all radioisotopic procedures. Radiopharmaceuticals are not used to produce a pharmacological effect. They all contain a radioisotope that is used for diagnostic imaging.

Technetium, an isotope, is one of the most important radiopharmaceuticals used in nuclear medicine today.

Because of its short half-life of six hours, technetium (99m) is used in nuclear medicine today for diagnosis, using the gamma camera. Since technetium lasts such a short time it cannot be kept in stock, so it is prepared by the beta decay of molybdenum. Molybdenum is kept in a shielded container while decaying, yielding technetium. It decays by a procedure called isomeric transition to a lower energy state, giving it a longer half-life. Every morning technetium is needed and extracted from its parent by a brine solution. This procedure is also used in other areas.

Radiopharmaceuticals play an important role in nuclear medicine. In diagnostic procedures small amounts of isotopes may aid in gaining necessary information concerning normal and abnormal life processes. The usage of these radiopharmaceuticals belongs under the supervision of the U.S. Atomic Energy Commission and licenses are issued only after institutions' facilities are inspected by the commission. Chart No. 2 on the previous page indicates the Radiopharmaceuticals used in diagnostic imaging and the standard adult doses for nuclear medicine scans.

## *Instrumentation*

There are a number of different radiation detection devices. The scintillation counter is by far the most widely used in nuclear medicine.

Scintillation counters consist of a detector system and a processing display unit. The detector system is made up of a sodium iodide crystal coupled to a photomultiplier tube. When gamma ray photons strike the crystal, flashes of blue-violet light or scintillation occurs. The crystal is transparent to light and it’s enclosed in a light tight container. A powder is used to reflect light out, only through the crystal area adjacent to the photomultiplier tube. Once the flashes of light reach the surface of the photomultiplier tube, electrons are released.

These electrons become amplified in the photomultiplier tube and are then transmitted through a preamplifier to the main unit only to be amplified further. Now the electrons are ready to be processed and displayed. The light emitted from the output signal from the detector unit is proportional to the energy released inside the crystal by way of the gamma photon.

Collimators play an integral part in detector systems. Collimators are designed so that the detector can only see photons in a specific area inside a patient while rejecting others from outside this area. The wide angle collimator is most commonly used and each type is designed for a specific purpose. When counts from a large field of view are needed the wide angle is used.

Parallel collimators are used with camera systems which also view a large area but are concerned mainly with the distribution of the radioactive isotope.

Focusing collimators are used with scanning devices which view a small area as in organ imaging. The collimator with more holes has what is called increased resolution, with decreased sensitivity and the opposite is true for a collimator with less holes.

The electrical pulses of electrons are directed to the processing unit from the detector system. The spectrometer is used to sort the spectrum of gamma energies and accept or reject ones of specific pulse height. The window must be adjusted to reject all pulses above and below certain energy levels. A window is the range of energy of an isotope. In the case of technetium, its energy range is 140Kev. The energy range is set up for 20% of the isotope, one will allow 10% above and 10% below the energy range. This will help to reduce the counts from scattered radiation.

From the spectrometer the information is passed on to be displayed as counts on a scaler. A scaler measures the amount of radioactivity from within the source.

Scanners are designed to produce two-dimensional pictures of the distribution of the radioactive isotope in an organ. Organ scanning is achieved by a systematic movement of a scintillation detection assembly with a focusing collimator, going back and forth across the organ of interest. These rectilinear scanners are now almost obsolete. The gamma camera is the number one imaging device that can produce an image without moving the detector unit. The camera has the ability to “see” certain organs in their entirety. A brief description of the Gamma Scintillation Camera and the Multi-crystal Camera follows.:

The three types of Collimators used in Nuclear Medicine

*(figure available in print form)*

Diagram of a Scintillation counter in simplified form

*(figure available in print form)*

## Diagnostic Imaging

Diagnostic imaging involves unstable atoms that disintegrate to release energy in the form of gamma rays. Any organ of the body can be scanned using radioisotopic procedures. The liver, bone, lung, thyroid and heart are the most often scanned in nuclear medicine today.

## Nuclear Medicine Scans

Liver/Spleen scans now account for approximately three-fourths of all nuclear medicine scans. Liver/Spleen scans are commonly used for displaying shape, size, position and any irregularities of the organ itself. A patient is injected with 6mCi of Technetium sulfur colloid. After fifteen minutes has elapsed the scanning procedure will begin. The particles emitted by the intravenous injection accumulate quickly in the cells of the liver long enough for several views of the liver and spleen to be taken. The views should include:.

a. Anterior aspiration with costal margin marker
b. Anterior expiration with costal margin marker
c. RAO—right anterior oblique
d. LAD—left anterior oblique
e. Anterior to include liver and spleen
f. Rt. Lat.—right lateral
g. Lft. Lat.—left lateral
h. Posterior to include liver and spleen

Any abnormalities such as abscess or lesions can be determined. A normal scan will demonstrate an even distribution of the radioactive isotope throughout the liver. Multiple views are taken, eight in all.

## *Perfusion Lung Scan*

The procedure is simple and accurate. A perfusion lung scan may show the flow of blood as far distal as the capillaries. This shows what parts of the lung are, and what parts are not, functioning. Before the perfusion scan is performed, a ventilation scan is done. Once the 4mCi of Technetium—MAA is injected, the distribution of the radioactive isotope will coincide with the pulmonary blood flow.

MAA better known as macroaggregated serum albumin is important to all nuclear medicine departments. MAA is commercially supplied in a sterile solution that is precalibrated for emergency situations. Six views of the lungs are taken as follows:.

a. LPO—left posterior oblique
b. Posterior
c. RPO—right posterior oblique
d. Right lateral
e. Anterior
f. Left lateral

## *Xenon — 133 Ventilation Scans*

Xenon is used for pulmonary ventilation scans. It shows how air moves in and out of the lung. This isotope is advantageous in that its 5.27 day half-life allows Xenon to be shipped without much loss of radioactive decay. Xenon—133 is being used as an inhalation method and can be administered safely due to its short biological half-life.

## *Gallium Scans*

Gallium scans are used in nuclear medicine for diagnosing abscesses, peritonitis and lung tumors. The patient is injected with 6-10 mCi of Gallium and the scan is usually obtained forty-eight hours after the injection. One can scan as early as twenty-four hours if the patient is susceptible to lesions in the lower abdomen area. Gallium scans are usually completed on a total body scanner. The areas of interest are the head, neck, chest and abdomen.

All nuclear medicine scans follow basically the same pattern. The patient is injected with the radioactive isotope. There is a time factor as to when the scan will begin. All types of views are taken of an organ at many different positions. The gamma camera is used for detection of all images.

It would be advantageous to use copies of scans in the classroom exercise. Copies of scans may be readily obtained through the Yale-New Haven Teachers Institute.

The following pages contain diagrams and the functions of the imaging devices in nuclear medicine.

## *Imaging Devices in Nuclear Medicine*

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### *The Scintillation Camera*

Only two stationary gamma-ray imaging devices have been commercially successful: the Anger scintillation camera (manufactured by Searle Radiographics, Picker, Ohio Nuclear, and General Electric, among others), and the Multi-crystal scintillation camera (manufactured by Baird-Atomic).

The Anger scintillation camera is shown schematically in Figure 1 on the following page. The scintillations produced in the sodium iodide detector are “looked” at by an array of 19 or 37 photomultiplier tubes (PMT). The scintillation light produced by a gamma-ray interaction in the detector crystal is shared by the PMT in the array. The contribution of H.O. Anger was to devise an electronic circuit which would produce an image dot on the face of an oscilloscope; the dot’s location corresponds to the location of the gamma-ray interaction in the circular detector. The first problem to be solved in the scintillation camera is the determination of the energy of the gamma ray. In a single PMT device (such as the rectilinear scanner), the pulse output from the PMT is proportional to the gamma-ray energy deposited in the scintillation detector. The same situation holds in the 19-tube array: the pulse size produced by each PMT is proportional to the light seen by that PMT. The output pulses of the 19 tubes are added together algebraically in the SUM circuit to form a SUM pulse, which is proportional to the total gamma-ray energy deposited in the crystal. The SUM pulse is sent to the pulse height analyzer, which produces an output pulse (called the Z-pulse) when the system has detected a gamma ray of the proper energy. This Z pulse is sent to an oscilloscope, where it causes one dot to be written on the face of the oscilloscope. A time exposure of the dot flashes is obtained to produce a scintophoto. If no additional information is provided by the system, a series of dots will be produced in the center of the oscilloscope; in other words, no localizing information is provided.

The information regarding where the dot is to be written on the face of the oscilloscope is produced by the X-, Y-position circuit. This circuit compares the pulse height output of each PMT with the SUM pulse. The position circuit produces X- and Y-deflection voltages which are applied to the deflection plates of the image oscilloscope. The process is illustrated schematically in Figure 2 on the following page. (The X-deflection plates are omitted for simplicity).

Figure 1.

*(figure available in print form)*

Figure 2.

*(figure available in print form)*

The result is a one-to-one correspondence between the location of the gamma-ray interaction on the face of the crystal and the location of the dot on the face of the oscilloscope. A scintiphoto then is a time exposure of a number of gamma-ray events. The time required for the system to process a gamma-ray interaction, from the first scintillation flash to the writing of the dot, is called the dead time of the system. The dead time is an important consideration when dynamic studies are performed, since it limits the rate of data accumulation, which in turn may limit the statistical accuracy obtainable during a dynamic study. The dead time characteristics of a number of scintillation camera systems is shown in the table on the next page.

## *The Multi - Crystal Camera*

In the multi-crystal scintillation camera, there is an array of 294 individual scintillation detectors, 14 rows and 21 columns, as indicated in Figure 3 on the next page. Gamma-ray interactions in the individual detectors produce scintillation light; the rows and columns are monitored by 35 light pipes connected to 35 phototubes. After some complex electronic checks to discriminate against simultaneous events in other crystals, the column and row address of the event is determined, providing an x- and y-address for the scintillation event. Note that detection and localization are independent.

In the normal course of events, the multi-crystal scintillation camera sends its output to 294 scalers, where the valid counts in each crystal are collected. The contents of these scalers are scanned and presented on the face of an oscilloscope as a scintiphoto where the brightness of the oscilloscope location is a function of the number of counts in each location. In a real sense, this device is a step ahead of the Anger scintillation camera in that its output has already been digitized—the number of counts in each location is represented by a number stored in a scaler.

## DEAD TIME AND ITS EFFECTS IN COLLIMATED IMAGING SYSTEMS (Highest Resolution Collimator)

| IMAGING SYSTEM | DEAD TIME Micro Seconds | COUNT RATE TO PRODUCE 10% LOSSES | $^{99m}$Tc ACTIVITY TO PRODUCE 10% LOSSES |
|---|---|---|---|
| Baird-Atomic System 70 | 2.3 | 100,000 cts/sec | 50 mCi |
| Searle LFOV | 2.0 | 90,000 cts/sec | 30 mCi |
| Picker 4/15 | 2.0 | 100,000 cts/sec | 33 mCi |

Figure 3.

*(figure available in print form)*

ANGER CAMERA OPERATIONAL STEPS

*(figure available in print form)*

*(figure available in print form)*

*(figure available in print form)*

## *Math in Nuclear Medicine*

In nuclear medicine basic mathematical principles are applied to practical situations. It is valuable in helping to perform the duties. Elementary calculus is helpful, but not really essential.

A good background in college level algebra is usually the minimum requirement. Presented below are some concepts and word problems which are particularly applicable to calculations frequently used in nuclear medicine.

## *Exponents*

I. The expression a = b , b is called the base and c is the exponent designating the power to which the base is raised. When working with exponents, three rules must be observed.

A) each factor may be evaluated separately and the individual products multiplied.

*EXAMPLE:*

$4^{2}$ = 4 x 4 = 16

$4^{3}$ = 4 x 4 x 4 = 64

THEN: 16 x 64 = 1024

The same results may be obtained by adding the exponents.

*EXAMPLE:*

$4^{2}$ x $4^{3}$ = 4(2 + 3) = $4^{5}$ = 1024

The above may be written algebraically as:

$X^{a}$ x $X^{b}$ x $X^{c}$ = $X^{(a + b + c)}$

II. The quotient of two terms containing the same base raised to any power is equal to the base raised to the difference of the algebraic sum of exponents in the numerator and the algebraic sum of the exponents in the denominator.

*EXAMPLE:*

$2^{4}$ Ö $2^{2}$ = ?

Evaluating the numerator and denominator separately, the results are as follows:

$2^4$ Ö $2^2$ = 16 Ö 4 = 4 or $2^4$ Ö $2^2$ = $2^{(4-2)}$ = $2^2$ = 4

The algebraic rule:

$Y^a$ $Y^b$ = $Y^a$ Ð b

III. One must multiply the exponents to raise a term to a power that has a base raised to a power.

*EXAMPLE:*

$(3^2)^3 = 9^3 = 243$, OR $(3^2)^3\ 3^{2t3} = 3^5 = 243$

***Math Activities for Students***

Write each of the following using exponents:

1. 6 . 6 . 6 = $6^3$

2. 4 . 4 . 4 . 4 = $4^4$

3. P . P . P . P . P = $P^5$

Evaluate each expression:.

1 Y = $7^2$ Y = 49

2. M = $3^5$ M = 243

3. T = $4^3$ T = 64

4. S = $2^4$ S = 16

Evaluate each expression:

1. $3y^4$ if y = 2 =

2. $4r^3$ if r = 3 =

3. $2m^3$ if m = 5 =

Simplify the following:

$$\frac{X^8}{X^5} \quad \frac{B^5}{B^2} \quad \frac{K^2}{K^7}$$

Simplify the following:

81 27 243

— = 3 — = 9 —— = 81
27 3 9

Gerald will be going to the hospital for a bone scan. He will arrive at the nuclear medicine department at 7:45 a.m. and be injected with l5mCi of Technetium—MDP. Scanning takes place two hours after injection is administered.

What time will Gerald's scan begin? *9:45 a.m.*

A survey showed that 3/4 of the patients of nuclear medicine receive liver and spleen scans. What part of the patients do not receive liver and spleen scans?

*.25* decimal *1/4* fraction
*25%* percent

Given the formula below, compute a childs dosage for a renal scan:

Child wt(kg) x Adult dose 60kg x 15
———————————Ð ————— = 13mCi
70kg 70kg

The following are problems for students. The purpose of these activities is to acquaint the student with units of measure required for computing mathematical computations with one or more operations related to nuclear medicine:

1. Sally mixes 260g of flour, 200g of sugar, and 245 grams of butter. How much does the whole mixture weigh? ———
2. Susan's dinner consists of 150g of cooked ham, 125g of potatoes, 100g of peas and 160g of fruit salad. How much does Susan's dinner weigh? ———
3. One apple weighs 100g and one orange weighs 160g. How much more than two apples do two oranges weigh? ———
4. A box of crackers weighs 342 grams. The crackers are packed in 3 cellophane wrappers. If each of the 3 packages has the same weight, how much does each package weigh? ———
5. Tammy's popsicle weighs 74g. How much does it weigh after Tammy has eaten half of it? ———
6. Jeff weighs 45kg and his baby brother weighs 5kg. How much more does Jeff weigh than his brother. Change the weight in kilograms to pounds. ———
7. Bob can lift twice as much weight as Carl. If Carl can lift 27kg, how much can Bob lift? ———
8. Lisa's bicycle weighs 3kg less than her wagon. If her bicycle weighs 8kg, how much does her wagon weigh? ———
9. An ocean liner weighs 31,000t. It takes on 78t of cargo, 65t of passengers and luggage, 43t of food and water. What is the total weight? ———
10. Cindy, Jimmy and Julie weigh 108kg all together. If Cindy weighs 23kg, Jimmy weighs 38kg, how much does Julie weigh? ———

## Resource List

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Dr. Ronald C. Ablow, M.D.

20 York Street

Diagnostic Imaging

Yale New Haven Hospital

New Haven, Connecticut

Diagrams of Imaging Devices courtesy of:

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