32.1 Diagnostics and Medical Imaging

Learning Objectives

By the end of this section, you will be able to:

- Explain the working principle behind an anger camera.
- Describe the SPECT and PET imaging techniques.

Most medical and related applications of nuclear physics are driven, at their core, by the difference between a radioactive substance and a non-radioactive substance. One of the first such methods is the precision measurement and detection method known as radioimmunoassay (RIA). Developed by Rosalyn Sussman Yalow and Solomon Berson in the late 1950s, RIA relies on the principle of competitive binding. For the particular substance being measured, a sample containing a radioactive isotope is prepared. A known quantity of antibodies is then introduced. By measuring the amount of ”unbound” antibodies after the reaction, technicians can detect and measure the precise amount of the target substance. Radioimmunoassay is essential in cancer screening, hepatitis diagnosis, narcotics investigation, and other analyses.

A host of medical imaging techniques employ nuclear radiation. What makes nuclear radiation so useful? First, γ radiation can easily penetrate tissue; hence, it is a useful probe to monitor conditions inside the body. Second, nuclear radiation depends on the nuclide and not on the chemical compound it is in, so that a radioactive nuclide can be put into a compound designed for specific purposes. The compound is said to be tagged. A tagged compound used for medical purposes is called a radiopharmaceutical. Radiation detectors external to the body can determine the location and concentration of a radiopharmaceutical to yield medically useful information. For example, certain drugs are concentrated in inflamed regions of the body, and this information can aid diagnosis and treatment as seen in Figure 32.2. Another application utilizes a radiopharmaceutical which the body sends to bone cells, particularly those that are most active, to detect cancerous tumors or healing points. Images can then be produced of such bone scans. Radioisotopes are also used to determine the functioning of body organs, such as blood flow, heart muscle activity, and iodine uptake in the thyroid gland.

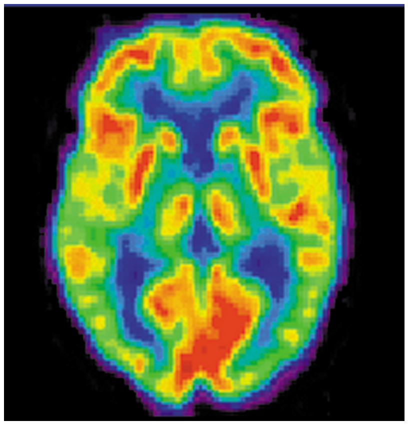

Figure 32.2 A radiopharmaceutical is used to produce this brain image of a patient with Alzheimer's disease. Certain features are computer enhanced. (credit: National Institutes of Health)

Medical Application

Table 32.1 lists certain medical diagnostic uses of radiopharmaceuticals, including isotopes and activities that are typically administered. Many organs can be imaged with a variety of nuclear isotopes replacing a stable element by a radioactive isotope. One common diagnostic employs iodine to image the thyroid, since iodine is concentrated in that organ. The most active thyroid cells, including cancerous cells, concentrate the most iodine and, therefore, emit the most radiation. Conversely, hypothyroidism is indicated by lack of iodine uptake. Note that there is more than one isotope that can be used for several types of scans. Another common nuclear diagnostic is the thallium scan for the cardiovascular system, particularly used to evaluate blockages in the coronary arteries and examine heart activity. The salt TlCl can be used, because it acts like NaCl and follows the blood. Gallium-67 accumulates where there is rapid cell growth, such as in tumors and sites of infection. Hence, it is useful in cancer imaging. Usually, the patient receives the injection one day and has a whole body scan 3 or 4 days later because it can take several days for the gallium to build up.

Procedure, isotope	Typical activity (mCi), where $1\ mCi = 3.7 \times 10^7$ Bq
Brain scan	
^{99m}Tc	7.5
^{113m}In	7.5
^{11}C (PET)	20
^{13}N (PET)	20
^{15}O (PET)	50

Procedure, isotope	Typical activity (mCi), where $1\ mCi = 3.7 \times 10^7$ Bq
^{18}F (PET)	10
Lung scan	
$^{99\text{m}}$Tc	2
^{133}Xe	7.5
Cardiovascular blood pool	
^{131}I	0.2
$^{99\text{m}}$Tc	2
Cardiovascular arterial flow	
^{201}Tl	3
^{24}Na	7.5
Thyroid scan	
^{131}I	0.05
^{123}I	0.07
Liver scan	
^{198}Au (colloid)	0.1
$^{99\text{m}}$Tc (colloid)	2
Bone scan	
^{85}Sr	0.1
$^{99\text{m}}$Tc	10
Kidney scan	
^{197}Hg	0.1
$^{99\text{m}}$Tc	1.5

Table 32.1 Diagnostic Uses of Radiopharmaceuticals

Note that Table 32.1 lists many diagnostic uses for $^{99\text{m}}$Tc, where “m” stands for a metastable state of the technetium nucleus. Perhaps 80 percent of all radiopharmaceutical procedures employ $^{99\text{m}}$Tc because of its many advantages. One is that the decay of its metastable state produces a single, easily identified 0.142-MeV γ ray. Additionally, the radiation dose to the patient is limited by the short 6.0-h half-life of $^{99\text{m}}$Tc. And, although its half-life is short, it is easily and continuously produced on site. The basic process for production is neutron activation of molybdenum, which quickly β decays into $^{99\text{m}}$Tc. Technetium-99m can be attached to many compounds to allow the imaging of the skeleton, heart, lungs, kidneys, etc.

Figure 32.3 shows one of the simpler methods of imaging the concentration of nuclear activity, employing a device called an Anger camera or gamma camera. A piece of lead with holes bored through it collimates γ rays emerging from the patient, allowing detectors to receive γ rays from specific directions only. The computer analysis of detector signals produces an image. One of the disadvantages of this detection method is that there is no depth information (i.e., it provides a two-dimensional view of the tumor as opposed to a three-dimensional view), because radiation from any location under that detector produces a signal.

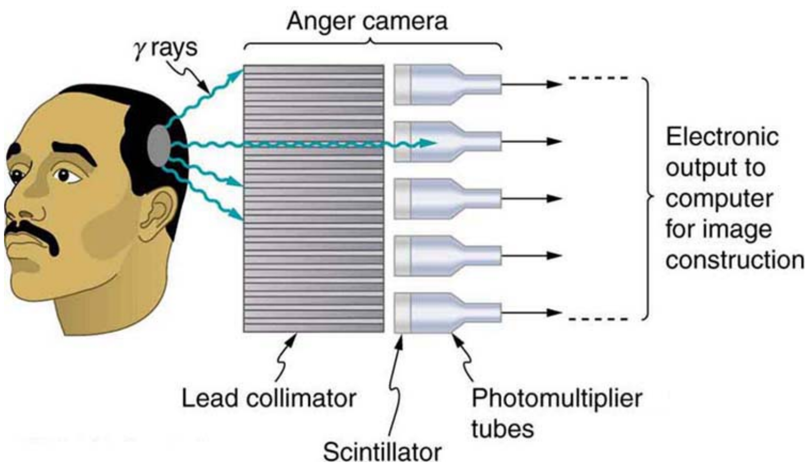

Figure 32.3 An Anger or gamma camera consists of a lead collimator and an array of detectors. Gamma rays produce light flashes in the scintillators. The light output is converted to an electrical signal by the photomultipliers. A computer constructs an image from the detector output.

Imaging techniques much like those in x-ray computed tomography (CT) scans use nuclear activity in patients to form three-dimensional images. Figure 32.4 shows a patient in a circular array of detectors that may be stationary or rotated, with detector output used by a computer to construct a detailed image. This technique is called single-photon-emission computed tomography(SPECT) or sometimes simply SPET. The spatial resolution of this technique is poor, about 1 cm, but the contrast (i.e. the difference in visual properties that makes an object distinguishable from other objects and the background) is good.

Figure 32.4 SPECT uses a geometry similar to a CT scanner to form an im-

age of the concentration of a radiopharmaceutical compound. (credit: Woldo, Wikimedia Commons)

Images produced by β^+ emitters have become important in recent years. When the emitted positron (β^+) encounters an electron, mutual annihilation occurs, producing two γ rays. These γ rays have identical 0.511-MeV energies (the energy comes from the destruction of an electron or positron mass) and they move directly away from one another, allowing detectors to determine their point of origin accurately, as shown in Figure 32.5. The system is called positron emission tomography (PET). It requires detectors on opposite sides to simultaneously (i.e., at the same time) detect photons of 0.511-MeV energy and utilizes computer imaging techniques similar to those in SPECT and CT scans. Examples of β^+ -emitting isotopes used in PET are ^{11}C, ^{13}N, ^{15}O, and ^{18}F, as seen in Table 32.1. This list includes C, N, and O, and so they have the advantage of being able to function as tags for natural body compounds. Its resolution of 0.5 cm is better than that of SPECT; the accuracy and sensitivity of PET scans make them useful for examining the brain's anatomy and function. The brain's use of oxygen and water can be monitored with ^{15}O. PET is used extensively for diagnosing brain disorders. It can note decreased metabolism in certain regions prior to a confirmation of Alzheimer's disease. PET can locate regions in the brain that become active when a person carries out specific activities, such as speaking, closing their eyes, and so on.

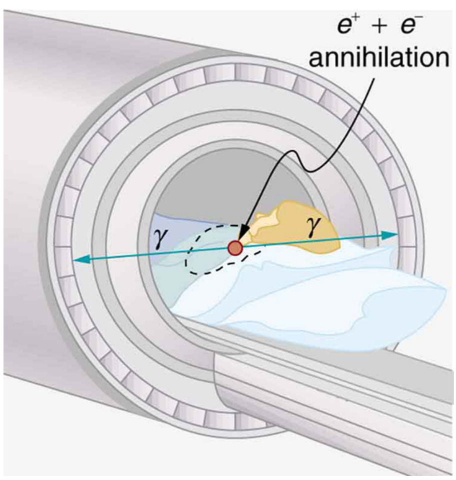

Figure 32.5 A PET system takes advantage of the two identical γ-ray photons produced by positron-electron annihilation. These γ rays are emitted in opposite directions, so that the line along which each pair is emitted is determined. Various events detected by several pairs of detectors are then analyzed by the computer to form an accurate image.

PhET Explorations

Simplified MRI Is it a tumor? Magnetic Resonance Imaging (MRI) can tell. Your head is full of tiny radio transmitters (the nuclear spins of the hydrogen nuclei of your water molecules). In an MRI unit, these little radios can be made to broadcast their positions, giving a detailed picture of the inside of your head.

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