R1.1 Detection and measurement of radioactivity: general introduction

When measuring the radioactivity of radiopharmaceutical preparations it is necessary to use standardized solutions of the appropriate radionuclide. Standardized solutions of radionuclides are available from laboratories recognized by the relevant national or regional authority (see General Notice on Reference substances).

When measuring the radioactivity of radiopharmaceutical preparations containing ^{99m}Tc, a good approximation may be obtained using an ionization chamber and employing a standardized solution of ^{57}Co provided that correction for the differences in the radiations emitted are made.

Radioactive decay may involve the emission of charged particles, the process of electron capture, or the process of isomeric transition. The charged particles emitted from the nucleus may be alpha particles (helium nuclei of mass number 4) or beta particles (electrons of negative or positive charge, beta $^-$ or beta $^+$ respectively, the latter known as positrons). The emission of charged particles from the nucleus may be accompanied by gamma rays, which are of the same physical nature as X-rays. Gamma rays are also emitted in the process of isomeric transition (IT). X-rays, which may be accompanied by gamma rays, are emitted in the process of electron capture (EC). Positrons are annihilated on contact with matter. Each positron annihilated is accompanied by the emission of 2 gamma rays, at 180 degrees to one another, each with energy of 0.511 MeV.

The methods employed for the detection and measurement of radioactivity are dependent upon the nature and energy of the radiation emitted. Radioactivity may be detected and/or measured by a number of different instruments based upon the action of radiation in causing the ionization of gases and solids, or the scintillation in certain solids and liquids, or by the effect of radiation on a photographic emulsion.

In general, a counting assembly consists of a sensing unit and an electronic scaling device. The sensing unit may be a Geiger-Müller tube, a proportional counter, a scintillation detector in which a photomultiplier tube is employed in conjunction with a scintillator, or a solid-state semi-conductor.

Geiger-Müller counters and proportional counters are generally used for the measurement of the beta emitters. Scintillation counters employing liquid or solid phosphors may be used for the measurement of alpha, beta, and gamma emitters. Solid-state devices may also be used for alpha, beta, and gamma measurements. The electronic circuitry associated with a detector system usually consists of a high-voltage supply, an amplifier, a pulse-height selector, and a scaler, a rate meter, or other readout device. When the electronic scaling device or the scaler in a counting assembly is replaced by an electronic integrating device, the resultant assembly is a rate meter. Rate meters are used for the purpose of monitoring and surveying radioactivity and are somewhat less precise as measuring instruments than the counters. Ionization chambers are often used for measuring gamma-ray emitters and, similar type of thin-walled instruments for measuring X-rays. Dose calibrators are ionization chambers used for measuring the amount of radioactivity in a vial or the dose to a patient in a syringe.

Radiation from a radioactive source is emitted in all directions that is, isotropically. Procedures for the standardization and measurement of such sources by means of a count of the emissions in all directions are known as 4π-counting; those based on a count of the emissions in a solid angle of 2π steradians are known as 2π-counting; and those based on a fraction of the emissions defined by the solid angle subtended from the detector to the source are known as counting in a fixed geometry. It is customary to assay the radioactivity of a preparation by comparison with a standardized preparation using identical geometry conditions. The validity of such an assay is critically dependent upon the reproducibility of the spatial relationships of the source to the detector and its surroundings and upon the accuracy of the standardized preparation. In the primary standardization of radionuclides coincidence techniques are employed in preference to simple 4π-counting whenever the decay scheme of the radionuclide permits. One of the most commonly employed coincidence techniques is 4π-beta/gamma coincidence counting, which is used for nuclides in which some or all of the disintegrations are followed by prompt photon emission. An additional adjacent detector, sensitive only to photons, is used to measure the efficiency in the 4π-counter of those disintegrations with which the photons are coincident. 4π-Gamma/gamma coincidence counting techniques are often employed for the standardization of pure gamma emitters.

The construction and performance of instruments and accessory apparatus could vary to a great extent. The preparation of samples must therefore, be modified to obtain satisfactory results with a particular instrument. The operator must carefully follow the manufacturer's instructions for obtaining optimum instrument performance. The results must be substantiated by careful examination of known samples. Proper instrument functioning and reliability must be monitored on a day-to-day basis through the use of secondary reference preparations.

Radioactivity occurring in materials of construction, or caused by cosmic rays, and to spontaneous discharges in the atmosphere contributes to what is known as the background activity. All sample radioactivity measurements must be corrected by subtracting the respective background activity.

When counting of samples at high activity levels, corrections must be made also for loss of counts due to inability of the equipment to resolve pulses arriving in close succession. Such coincidence-loss corrections must be made prior to the background correction.

The corrected count rate, R, is given by the formula:

$$R = \frac{r}{1 - r\tau}$$

Where r is the observed count rate, and τ is the resolving time.

A radioactivity count is a statistical value, i.e., it is a measure of nuclear decay probabilities, and is not exactly constant over any given time interval. The magnitude of the standard deviation is approximately equal to the square root of the number of counts. In general, at least 10 000 counts are necessary to obtain a standard deviation of 1%.

Absorption

Ionizing radiation is absorbed in the material surrounding the source of the radiation. Such absorption occurs in air, in the sample itself (self-absorption), in sample coverings, in the window of the detection device, and in any special absorbers placed between the sample and the detector. Since alpha particles have a short range of penetration in matter, beta particles have a somewhat greater range, and gamma rays are deeply penetrating, identification of the type and energy of radiation emitted from a particular radionuclide may be determined by the use of absorbers of varying thickness. In practice, this method is seldom used, and that too mainly in connection with beta emitters. Therefore, variations in counting rate due to (small) differences in thickness and density of sample containers could give rise to major problem with beta emitters and with X-ray emitters, such as iodine-125. Plastic containers, in which variations of density and thickness are minimal, are therefore often employed in such cases. Plastic tubes with defined density and thickness are therefore employed frequently.

The absorption coefficient (μ), which is the reciprocal of the “thickness” expressed in mg/cm^2, or the half-thickness (the thickness of absorber required to reduce the radioactivity by a factor of two), is commonly determined to characterize the beta radiation emitted by a radionuclide. This equation is valid only for monoenergetic radiation.