Nuclear Medicine
Detector Applications Information Note

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Radiation detectors play a major role in non-invasive clinical investigations.

In nuclear imaging, imaging systems called gamma cameras determine the radiation distribution, transit time or uptake of a pharmaceutical labeled with a suitable, short-lived radioactive nuclide administered to the patient. The camera's externally placed radiation detectors measure the radiation, and special imaging devices display the radioactivity distribution. The images yield information about the function of an organ or part of the body. SPECT and PET are two of the imaging techniques used.

In X-ray diagnostics, the transmitted intensity of an X-ray beam is measured. The standard technique of irradiating the patient with an X-ray beam and producing an image on photographic film is still widely used. However, the availability of advanced computers and sophisticated radiation detection and image processing techniques has led to the development of digital radiographic imaging sytems – CT scanners. These systems measure the transmitted radiation with an array of radiation detectors. The signals from the arrays are used to construct a density image that can be analyzed using computer techniques.

In Radioimmunoassay (RIA) measurements, isotopes of Iodine (I-125, I-132) or other radionuclides are used to label organic molecules in samples taken from the patient. Analyzers incorporating single or multiple small NaI(Tl) well detectors count the activity in the samples to determine the presence of certain agents. This information can help in diagnosing certain conditions.

Planar and Single Photon Computerized Tomography (SPECT) Gamma Cameras

In nuclear medicine, it is often necessary to view the image of the distribution of γ-ray-emitting isotopes throughout the patient. The gamma camera is a device that senses the two dimensional coordinates of a γ-ray photon as it interacts in a large-area detector. It forms an image through the accumulation of many such events over the exposure time. A pin-hole or parallel hole lead collimator restricts the γ-rays that strike the detector so that an image of the two-dimensional radioactivity distribution is projected on the scintillation crystal. A matrix of photomultiplier tubes mounted on the back of the scintillation crystal detects the scintillation light. The original gamma cameras incorporated a single NaI(Tl) flat crystal. To increase patient throughput and improve resolutions, systems have been designed with larger and/or multiple crystals. By using two or more large area detectors and by rotating them around the patient, a three-dimensional image of the radioactivity distribution can be obtained. This technique is called SPECT.

Photon statistics play an important role in determining the position of an interaction event accurately. Because of the rather low radiation energies detected, NaI(Tl) with its high light output is the preferred material, at present, for detectors used in these applications.

Recently, SGC developed sodium iodide, optically isolated arrays for use in portable, organ-specific gamma camera systems. The geometry ensures superior light output and maximizes the field-of-view.
In general, the demand is for NaI(Tl) scintillation crystal detector plates in sizes up to 80 cm (31.5"), in cylindrical or rectangular geometries. Larger sizes can be made. Since Tc-99m, which emits 140 keV γ-rays, is the nuclide most often used, a crystal thickness of 1cm is sufficient. However, using thicker plates allows 511 keV studies to be done as well.

Positron Emission Tomography (PET)
The PET technique evolved in the mid-1970's and uses positron emitting isotopes (e.g. C-11, O-15, F-18) to study chemical and biological processes in the body. The primary β+ radiation that these nuclides emit cannot penetrate far in tissue – only a few millimeters. When a positron has slowed down in the surrounding material to nearly rest, it will annihilate with an electron, creating two nearly co-linear 511 keV gamma rays.

By setting a coincidence requirement on two opposing scintillation detectors, measuring only 511 keV quanta, and by accumulating several events, information about the position of the nuclide in the object can be obtained. A full tri-dimensional image of the radioactivity distribution can be obtained using advanced imaging techniques. With PET, images of biologically active compounds can be made for studying metabolic processes.

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PET detectors require that the detector material be of high enough Z to maximize the photoelectric cross sections for 511 keV, be fast enough to handle the count rates involved, and be able to distinguish coincident events. Furthermore, detectors for PET should show a reasonable pulse height resolution for 511 keV so that scattered events in the patient can be rejected.

Early PET scanners used NaI(Tl) scin-tillation crystal detectors, but many current devices are equipped with BGO and other scintillators. The subsequent trend toward higher count rates then made scintillators such as CsF, BaF_2 and undoped CsI (all relatively fast but with low light output) more attractive.

When using ultra-fast scintillators, Time of Flight Positron Emission Tomo-graphy (TOF PET) becomes possible. In this technique, the difference between the moments of interaction of the two annihilation quanta provides information on the position of the annihilation. Time-of-flight information also allows the rejection of annihilation events outside a selected area. This improves the signal-to-noise ratio.

In 1998, the Federal government began to approve reimbursement for several PET imaging procedures. This opened the door for more aggressive development in this modality. NaI(Tl) regained popularity in PET applications due to its high light output, lower cost and dual-energy capability.

In 1998, UGM Medical introduced a dedicated PET system using a curved NaI(Tl) detector developed at Saint-Gobain. Besides bringing the detector closer to the body across the field of view (versus conventional flat plates), there is a reduction in the parallax error due to the more consistent distance between an event and the PMT.

Gamma camera manufacturers also responded to this reimbursement by introducing cameras that could image in both SPECT and PET modes using thicker NaI(Tl) crystals. Thicker crystals, while improving high energy efficiency, tended to degrade low energy performance. SGC devloped a slotted NaI(Tl) detector to address this need. Slots cut into the NaI(Tl) crystal direct light to the photomultiplier tubes which otherwise would be internally reflected. This increases the forward acceptance angle of light and reduces the light spread. This innovation allows for excellent SPECT performance while still maintaining the improved efficiency for PET.

Today, most PET systems are using denser materials such as BGO or Lutetium-based scintillators. LYSO combines a short decay time, high light output and good energy resolution and is a good candidate for PET applications. $LaBr_3$ crystals are also of strong interest to achieve ultra-low Coincidence Resolving Times (CRT's).

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