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COLLEGE ON MEDICAL PHYSICS

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Nuclear Electronics Application in Nuclear Medicine Instrumentation

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The instrumentation of nuclear medicine is primarily involved in detecting, registering, and localizing nuclear decay effects. Actually nuclear cannot be detected by simply observing the event, but the effect of the nuclear radiation is measured. The fact that nuclear decay events at a remote site (in vivo or in vitro) can be detected by the consequent effects of individual photons or particles makes the indicator method with radionuclides very valuable in diagnosis.

I. instrumentation for Nuclear Medicine

There are various nuclear instruments in medical research institutes and hospitals. Some examples follow:

- measurement of thyroid uptake
- renography
- whole body counters
- liquid scintillation counters
- rectilinear scanners
- gamma cameras
- radioimmunoassay

Nuclear dosimetry and protection instruments are very often used in hospitals, but they have some features which are a little bit different from scanning and imaging in nuclear medicine.

II. Characteristics of Nuclear Medicine Instrumentation

1. Measuring accuracy is closely related to statistical quantity. We do not wish to measure only a single nuclear decay event, but the total activity of a radionuclide substance. Therefore counting of nuclear decay events leads to decay rate, i.e. as nuclear decay number per time interval, for establishing an activity value.

2. Sensitivity is very important to in vivo diagnosis. A lot of efforts of developing nuclear diagnosis are put to increase system sensitivity and to shorten the time intervals between two measurements.

3. It is important to bear in mind the stepwise change of the measuring effects since the value of the final results depends on the accuracy of the relation of the measuring effects of the various stages to each other.

4. Distorted measurements by the material surrounding the source.

5. background measurement and shielding.

6. Space relation and collimator in nuclear imaging.

7. Radiation measurement with scintillation detector and relevant electronic circuitry is of practical importance in nuclear-medical diagnosis, especially NaI detector and relevant systems.

III. Solid Scintillation Counting

A scintillator is a substance that emits a small flash of light when struck by a fast, charged particle. An example is (Ag) ZuS hit by an alpha ray.

Solid scintillators are particularly suitable for the detection of gamma rays (besides X-rays) because of the high density and high-Z of certain solid crystals. Fig. 1 shows a typical scintillation crystal detector.

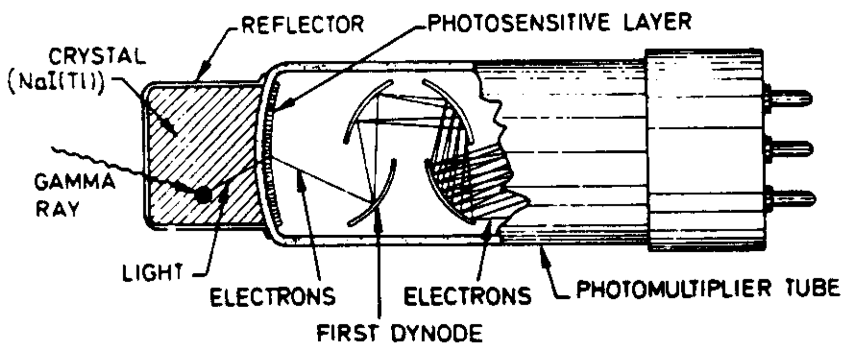

Fig. 1. A typical scintillation detector

The mechanism of the detection and energy change from r-ray ---. light photons ---. electronic pulses, can be illustrated in fig. 2.

Radioactive source ---» emission of characteristic energy

proportional
energy transfer

Scintillator ---» photon emission

proportional
energy transfer

Photon sensitive device ---» photoelectron release

proportional
energy transfer

Pulse processor ---» electronic pulses

proportional
energy transfer

Pulse height analyzer ---» acceptance of defined pulses

pulse transfer

Scaler or ratemeter ---» indicates number of acceptable pulses

Fig. 2. Generation of photons from elemental disintegration to counters

Observed gamma-ray spectrum can be typically shown in Fig. 3 and has two important parts:

1. Total absorption peak caused by total absorption of the gamma-photon energy within the crystal.

2. Compton region caused by the scattered photon escapes from the detector.

The location of the total-absorption peak is characteristic of Er and is useful in identifying the corresponding gamma-ray emitter in any sample. The area under the total-absorption peak is proportional to the activity of that radio nuclide in the sample. The peak is actually broadened into a distribution due to (a) instrumental broadening ,and (b), statistical broadening as a result of the several conversion steps from gamma-photo absorption to final pulse.

Compared with other kinds of radiation detectors, NaI has the following advantages:

1. r-ray spectrum measurement with few absorption peaks

2. high efficiency

3. very short resolving time of such system, i.e. higher count rate

4. simple, relatively cheap, and rugged

These are the reasons why scintillators are widely used in various areas, especially in nuclear medicine.

Appendix 1 shows an example of a scintillation detector in the single channel analyzer system used by the IAEA.

IV. Signal Processing

Both scintillation and semiconductor detectors provide pulses which are too small to operate recording equipment directly without conversion to pulses of sufficient amplitude and suitable shape. This requires amplifier as follows:

1. A variable gain of 50 - 3000 times, providing output in the range of 1 - 10 V.

2. Linearity, so that the size of the input pulse is directly proportional to that of the output pulse, thus preserving information on pulse height.

3. Stability. The gain should not vary significantly with changes in ambient temperature or small variations in supply voltage.

4. Pulse shaping for avoiding pulse superimposing

Appendix 2 shows an example of an amplifier in a single channel analyzer system used by the IAEA.

V. Pulse-Height Discriminators and Analyzers

The pulses from the main amplifier should retain the proportionality between pulse size and energy absorbed in the detector.

There are three kinds of pulse-height analyzers:

1. Pulse height discriminator against background and low energy scatter.

2. Single-channel analyzer. It consists of two pulse-height discriminators for just acceptance of the pulse filled into "windows."

3. Multi-channel analyzer. A hundred or a thousand of single-channel analyzers are connected in parallel.

Appendix 3 shows an example of a single channel analyzer used by the IAEA.

VI. Pulse Recording

The pulses which pass the discriminator or pulse window are of a constant size and may be recorded in a variety of ways:

1. Ratemeter

2. Scaler and timer

3. Recorders

Appendix 4 shows examples of a ratemeter and a scaler/timer in a single channel analyzer system used by the IAEA.

VII. Shielding and Collimator

Usually, detectors are provided with lead shielding to prevent background radiation from influencing the measurement result. Collimators also have a directional effect since only a certain spatial angle is now open for picking up the radiation.