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The Detector Efficiency in Radiation Measurement and a Practice in Nuclear Medicine

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ABSTRACT

The sensitivity of detector mainly depends on two parameters as energy resolution and detection efficiency. In the studies made with radioisotopes, particularly the high detection efficiency allows for conducting high quality medical operations with low radiation doses. While today highly-advanced imaging systems are effectively used in the nuclear medicine studies, the use of some conventional counting systems such as thyroid uptake probe are continued effectively. A NaI(Tl) scintillation counter is used in the thyroid uptake probe for detection of radiation and this detector is one of detector types which is very frequently used in the measurement of gamma rays. In this study, some of parameters leading to the efficiency of thyroid uptake probe was measured by taking its significance mentioned above in consideration. The count rate was calculated based on these results and these count rates were compared with the count rates measured.

Key words: Efficiency, Thyroid Uptake Probe, Nuclear Medicine, Radiation

1. INTRODUCTION

In the today's medicine imaging and practices, the high efficiency and high resolving powered scintillations or semi-conductor detectors are required for detection of x-ray or gamma ray. However, there is no such a detector practice which ensures these two basic parameters at the same time and at desired level, yet. The studies to develop a new type of detector which will provide these two parameters at optimum level are continued [1].

The sensitivity of detector mainly depends on two parameters as energy resolving power and detection efficiency. The scintillation counters are one of detector types which is very frequently used in the measurement of gamma rays. The scintillation counters are constituted from two parts as scintillator and photomultiplier tube. The gamma ray received by detector first interacts with NaI scintillator substance. The atom which remained excited at the end of interaction, leads to photon emission in the visible region when it switches into ground state. The intensity of emitted photons is directly proportional to the energy of gamma interacted with detectors. The emitted photon is converted into electron in the photomultiplier tube and a pulse measurement is made (Figure 1). The probability of photon's which hit to the detector window, taking place in photopic determines the efficiency of detector. The calibration of efficiency obtained as the function of energy is necessary for determination of real activity of source. The detector efficiency is divided into two parts as absolute and intrinsic. The absolute efficiency yields the probability of measuring the gamma rays emitted from source. The intrinsic efficiency yields the probability of measuring the photons which hit the detector.

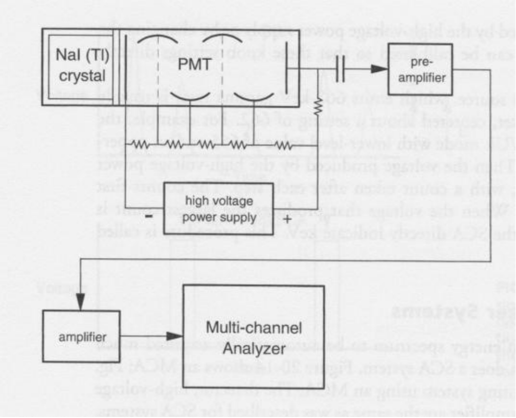

Figure 1. The counting operation in NaI(Tl) scintillation counter

While the detectors given in Table 1 are used for radiation measurement, NaI(Tl) and semi-conductor detectors are mostly used in the measurement of gamma radiation. In the nuclear medicine practices, the NaI(Tl) detectors are mostly used. While some of these devices at which these detectors are used are designed for in-vitro studies, some of them are designed for in-vivo studies. Today, a significant part of nuclear medicine studies consists of taking the image of distribution of radioactive substance given to patient, into the organ. These devices which are designed for these purposes, shall have significant characteristics. In this regard, the efficiency is one of most significant characteristics for a measurement device. It is possible to obtain maximum information with minimum radiation thanks to high efficiency. The count rate of device is another significant parameter. When the efficiency and count rate is not at desired level, these leads to data losses and some data contaminations. This sometimes gives misleading and sometimes low-quality results.

Table 1 Classification of detectors [2]

Type	Detectors
Electric	Ionization Chamber
	Proportional Counter
	Geiger-Muller Counter
	Semi-conductor detector
	Neutron Detector
	Scintillation Counter
	Cerenkov Counter
Optical	Photographic Emulsion
	Expansion Cloud Chamber
	Diffusion Cloud Chamber
	Bubble Chamber
	Spark Chamber

2. DETECTION EFFICIENCY

2.1. Components of Detection Efficiency

The detection efficiency determines the capability of a radiation measurement device to convert the radiation emitted from the source, into useful signals. Where a gamma source of which activity is A(Bq) emits η unit gamma per fraction, the emission rate of source ξ will be as follows:

$$\xi(\gamma \text{ rays/sec}) = A(\text{Bq}) \text{x} 1(\text{dps/Bq}) \text{x } \eta((\gamma \text{ rays/dis}) \quad (1)$$

Where the count rate emitted from this source is R [counting per second(cps)], the detector efficiency can be expressed as follows:

$$D = R/\xi \quad \text{and} \quad R = D\text{x } \xi \quad (2)$$

It is desirable that this value should be as high as possible. This may be only possible with low ξ and high R count rate.

Detection efficiency is affected by several factors, including the following:

1. The *geometric efficiency*, which is the efficiency with which the detector intercepts radiation emitted from the source. This is determined mostly by detector size and the distance from the source to the detector.
2. The *intrinsic efficiency* of the detector, which refers to the efficiency with which the detector absorbs incident radiation events and converts them into potentially usable detector output signals. This is primarily a function of detector thickness and composition and of the type and energy of the radiation to be detected.
3. The fraction of output signals produced by the detector that are recorded by the counting system. This is an important factor in *energy-selective counting*, in which a pulse-height analyzer is used to select for counting only those detector output signals within a desired amplitude (energy) range.
4. *Absorption and scatter* of radiation within the source itself, or by material between the source and the radiation detector. This is especially important for in vivo studies, in which the source activity generally is at some depth within the patient.

In theory, one therefore can describe detection efficiency D as a product of individual factors,

$$D = g \text{ x } \varepsilon \text{ x } f \text{ x } F \quad (3)$$

where g is the geometric efficiency of the detector, ε is its intrinsic efficiency, f is the fraction of output signals from the detector that falls within the pulse-height analyzer window, and F is a factor for absorption and scatter occurring within the source or between the source and detector [3].

2.2 Geometric and Intrinsic Efficiency

As illustrated in Figure 2, a detector with surface area *A* placed at a distance *r* from a point source of radiation and facing toward the source will intercept a fraction $A/4\pi r^2$ of the emitted radiation. Thus, its geometric efficiency g_p is

$$g_{p=}\ A/4\pi r^2 \tag{4}$$

and

$$A = \pi d^2\ /4 \tag{5}$$

When equation (4) and (5) are evaluated together, this will be obtained:

$$g_{p=}\ d^2/16r^2 \tag{6}$$

The intrinsic efficiency of the detector is the number of radiations interacting with the detector divided by the number of radiations striking the detector. So,

$$\varepsilon_{=} \text{ no of radiations interacting with detector/ no of radiations striking detector} \tag{7}$$

For a point source located on the central axis of a γ-ray detector, it is given by

$$\varepsilon = 1\text{-}e^{-\mu l\ (E)\ x} \tag{8}$$

where $\mu_l\ (E)$ is the linear attenuation coefficient of the detector at the γ-ray energy of interest, *E*, and *x* is the detector thickness.

Photofraction (f) is the number of counts in the photopeak divided by the total number counts. So,

$$\text{f= number of counts in the photopeak/ the total number counts} \tag{9}$$

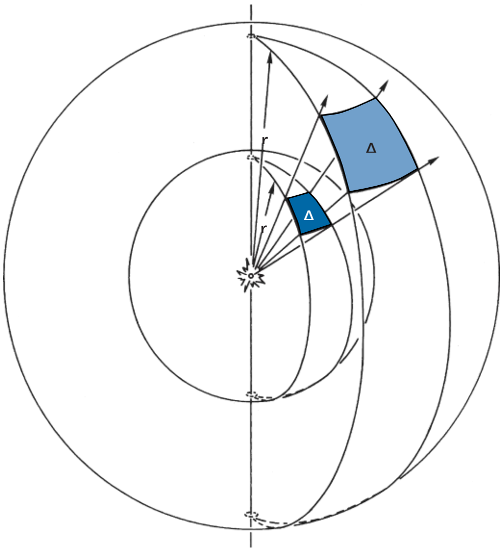

Figure 2. Illustration of the inverse-square law. As the distance from the radiation source increases from r_1 to r_2, the radiations passing through A_1 are spread out over a larger area A_2. Because A α r^2, the intensity of radiation per unit area decreases as $1/r^2$ [3, p:157]

3. MATERIAL AND METHOD

The study was conducted in a nuclear medicine center which was carrying out patient activities effectively. The thyroid uptake probe shown in Figure 1 was used for obtaining all data. This probe is a device used for evaluating the structure and functions of thyroid gland. Although very sensitive and special in-vitro tests were developed, the thyroid gland uptake studies have still playing a significant role in the determination of causes of specifically ectopic thyroid tissue, functioning single or multiple nodules and thyrotoxicosis clinically [4]. The first agent used in the thyroid uptake studies was iodine-131. The I-131 studies has significant disadvantages in terms of thyroid gland which are resulted from long half-life and particle scattering [5]. The iodine-123 (I-123) is an isotope which may be substituted with I-131. This is because the half-life of I-123 is shorter and its image quality is high at scintillation cameras. However, it has disadvantages such as being expensive and difficulty of availability [5, 6]. The technetium 99m (Tc-99m) pertechnetate is widely used not only for thyroid scintigraphy but also in the thyroid uptake studies successfully [7-8]. The Tc-99m pertechnetate is a radioisotope which is most widely used for evaluation thyroid functions in the world since it has some advantages such as not having β radiation, having a short half-life such as 6 hours and its short retention period in the thyroid gland. Other significant advantages of Tc-99m pertechnetate are as follows: the energy of its gamma photon is 140 keV and it is cheap and easily accessible [9].

Figure 3. Thyroid Uptake Probe

Obtaining desired results from thyroid uptake device which has been still used in significant studies mentioned above, exactly depends on the efficiency of detector used at the device. Therefore, it is important to determine the detector efficiency with radioactive source shaving different energies. In this study, the radioisotopes with different energies were used by taking this significance in consideration and some parameters yielding the efficiency of detector were obtained experimentally and the count rates calculated from these values were compared with the values measured. The radioisotopes which were used, and their energies are given below.

Table 2. The radioisotopes which were used in the study and their energies

Isotope	Energy	
Cs-137	662	keV
Tc-99m	140	keV
Co-57	122	keV
Na-22	1274	keV
Co-60	1173	keV
	1332	keV
I-131	364	keV

All measurements made with the aim of obtaining the detection efficiency were obtained by using the radioisotope energies given in Table 2 and 5 cm X 5 cm NaI(T1) scintillation counter available on Thyroid Uptake Probe.

4. RESULTS

In this study, the data were obtained by using radioisotopes given in Table 2. The measurements at specific distances were taken from detector for each standard point source. All calibrations of device were made before the measurements and the background counts were taken in consideration in count statistics for each count. The results and calculation results of measurements are given in Table 3 and Table 4.

Table 3. gp and f values for isotopes having different activities and energies

.Isotope	Distance of Source to Detector (cm)	g_p(geometric efficiency)	f(photofraction)
Cs-137 (662 keV) A=8.97 µCi	8	0.025	218499/420192=0.52
	14	$8.2x10^{-3}$	74236/139123=0.53
	20	$4.03x10^{-3}$	37129/70054=0.53
	26	$2.38x10^{-3}$	22054/42411=0.52
	32	$1.57x10^{-3}$	15726/29671=0.53

Similarly, the measurements were made with other isotopes and the results given in Table 4 were obtained.

Table 4. g_p and f values for isotopes having different activities and energies

Isotope	f	Isotope	f	Isotope	f
Co-57 (122 keV) A=1.8 µCi	0.98	Co-60 (1332 keV) A=5.54 µCi	0.27	I-131 (364 keV) A=30.0 µCi	0.75
	0.98		0.26		0.76
	0.98		0.26		0.75
	0.97		0.26		0.76
	0.97		0.27		0.75
Co-60 (1173 keV) A=5.54 µCi	0.34	Na-22 (1274 keV) A=2.86 µCi	0.30	Tc-99^m (140 keV) A=36.3 µCi	0.94
	0.34		0.30		0.94
	0.34		0.29		0.95
	0.34		0.30		0.94
	0.34		0.30		0.95

The $R_{theoratical}$ count rates were obtained with the help of equation (2) and (3) by using g_p and f values given in Table 3 and 4 (F=1) and the results were compared with $R_{meaured}$ count rates. the results are given in Table 5.

Table 5. R_{me} and R_{the} values for isotopes having different activities and energies

Isotope	R_{me}	R_{the}	Isotope	R_{me}	R_{the}	Isotope	R_{me}	R_{the}
Co-57 (122 keV) A=1.8 µCi	84117	83804	Cs-137 (662 keV) A=8.97 µCi	218499	220043	I-131 (364 keV) A=30.0 µCi	900103	873792
	28972	28048		74236	73460		296156	295997
	14768	13509		37129	36053		143206	145267
	8679	7896		22054	14048		86142	84809
	6734	5209		15726	14048		57009	56250
Co-60 (1173 keV) A=5.54 µCi	64336	68996	Na-22 (1274 keV) A=2.86 µCi	31936	31428	Tc-99 (140 keV) A=36.3 µCi	1716036	1685456
	21542	22629		10935	10285		554739	552829
	12541	11118		4910	4888		275136	274585
	7348	6518		3115	2984		159634	160455
	4718	4329		2028	1968		103839	106972

4. CONCLUSION AND DISCUSSION

All data of study were obtained from a licensed nuclear medicine center which had effective and dense patient admittance. The study was conducted by using scintillation counter which is one of very frequently used detector types in the measurement of gamma rays. In the study, the data were obtained by using ‘’Thyroid Uptake’’ device which had 5 cm X 5 cm NaI(T1) scintillation detector. While today the highly advanced imaging systems are used in the medicine studies effectively, the use of some conventional counting systems such as thyroid uptake probe, by which the measurements were taken in the study, are continued effectively. Moreover, the detectors, either highly complicated imagining systems or simple systems only containing counting systems, are operated based on same principle and they shall have some basic characteristics. These are the efficiency and count rate which are most important features determining the quality of counting operation. Anyway, these are closely correlated. In the study, the count rate calculations were made by measuring some part of efficiency parameters by taking this close relationship in consideration and these results were compared with the count rates directly measured. It was considered that the conformity of this relationship will give an opinion on efficiency of detection and it was seen that the results were in compliance.

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