QUALITY CONTROL OF THE KORLE BU RECTI-LINEAR SCANNER

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ABSTRACT

The attainment of high standards of efficiency and reliability in the practice of nuclear medicine requires an appropriate quality assurance programme. The routine monitoring of nuclear medicine instruments, using test procedures that provide check of the quality and reproducibility of instrument performance, aims at giving the user the confidence in the data collected and in updating the performance of the instrument.

Quality control testing schedule for rectilinear scanners include weekly density calibration and monthly performance contrast enhancement and collimator evaluation. Discussion in this work is however, restricted to collimator evaluation which is required to be performed at the initial stages of installation as acceptance reference. However unlike the density, calibration and contrast enhancement, there is no documented work on this for the M800 Scintikart Scanner - a Hungarian Gamma Muvek system belonging to the Korle Bu Hospital, Accra.

Tests of linearity of energy, relative sensitivity and resolution including energy and spatial resolutions were conducted in respect of collimator evaluation. In the linearity test it was ascertained that a nonlinear relationship exists between the centre of the window setting and the energy of the photopeak. The spectrometer was calibrated independently for each radionuclide and the position of Tc-99m obtained at .045 MeV on the MeV scale. In addition the F272 al3 Collimator offered a better resolution than the routinely used F272 a136 collimator which has the highest sensitivity.

Keywords: Collimators, sensitivity, resolution

INTRODUCTION

The scanner is a mechanical instrument of partially independent components - the head, amplifier, pulse height analyzer (PHA), scaler or ratemeter, display processor, high voltage source and display device - all designed to produce a two dimensional image of the distribution of radioactivity of a gamma source by scanning the region of interest in successive rectilinear passes.

The collimator detector containing thallium activated sodium iodide (NaI(T1))crystal scintillator converts gamma radiation from the source into light pulses. The light pulse in turn produces electrons from a photocathode of the photo multiplier tube. The electrons are then multiplied by a dynode system resulting in electron avalanche which in turn produces current pulses on the anode. These current pulses are then amplified and transmitted to the PHA. Pulse amplitude is proportional to the energy absorbed in the scintillator and pulse frequency to the intensity of radiation [1]. The PHA discriminates the energy that passes. The output pulses from the PHA are further transferred by a display processor and then fed to the display devices which are rigidly connected to the scanner head. In addition, controls for scanner speed, line spacing, selection of background erase, fixed programmes for discriminator of isotopes, and the size of the scan area can be pre-selected.

Quality control refers to the assessment, maintenance and optimisation of the performance of the instrumentation. Nuclear medicine now has a well-established place in health care, and workers in the field must ensure the maintenance of standards so that the patient benefits from the best service which the techniques and instrumentation can give. Careful control of the performance of the scanner will contribute to this process.

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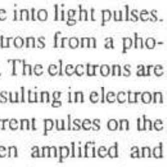

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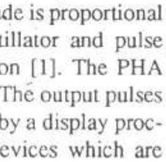

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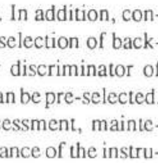

Test of Linearity

Linearity of a spectrometer of the scanner describes the relation between the size of the voltage pulse produced by total absorption of photons in the crystal and the centre-of-the window setting (photopeak) necessary to observe the pulse.

To evaluate the linearity, the window setting that encompasses the centre of the photopeak was determined using Na(0.511, 1.275MeV), Cs-137 (0.662MeV) and Mn(0.835MeV) point sources at a working voltage of 800V.

A graph of the centre of the window setting against energy of the photopeak gave a straight line (Fig.1). The centre of the window for Tc-99m (140keV) was found by extrapolation to be 45keV on this scale. This was verified using Tc-99m point source to give 45±6keV on the spectrometer. None of the other scales was able to detect Tc-99m.

Resolution

In nuclear medicine, resolution is defined as the capability to distinguish the fine detail needed to identify small inhomogeneities in radionuclide distribution. In this work both spatial and energy resolutions were measured.

Test of Spatial Resolution

To measure the spatial resolution in scanning, a line source is employed in place of light source as obtains in Physics of optics - wherein the difficulty of precisely aligning the collimator and the point source is avoided. The Line Spread Function (LSF) data, the concepts of Full Width at Half Maximum (FWHM) and the derived Modulation Transfer Function (MTF) are used as a measure of the spatial resolution of the detecting system [2.3]. The FWHM is defined as twice the distance by which a point source must be placed from the axis of the collimator at the working distance in order to reduce the

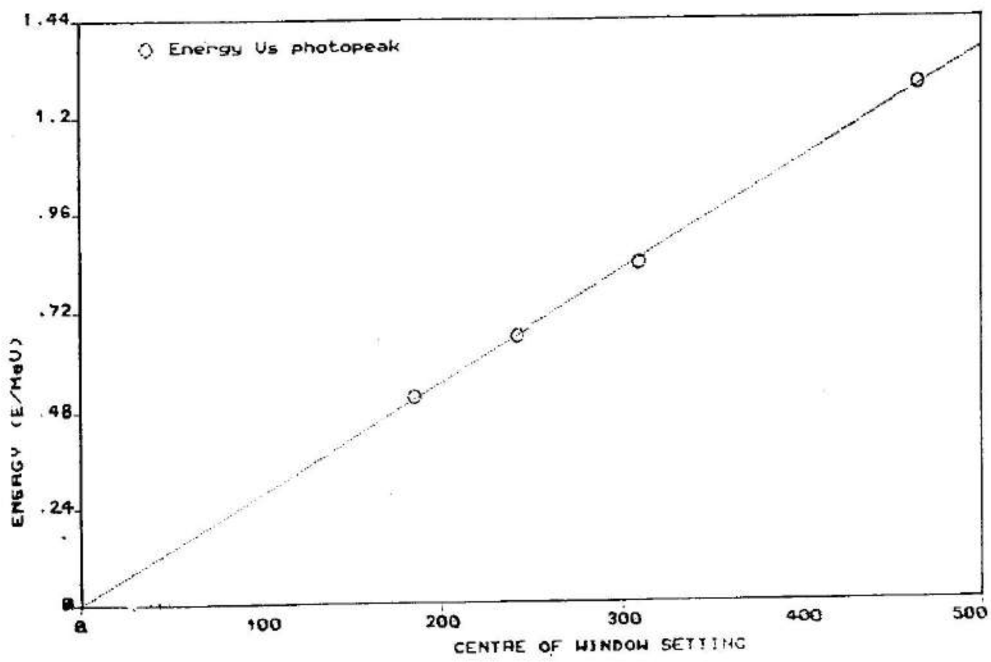

Fig. 1 Energy Calibration

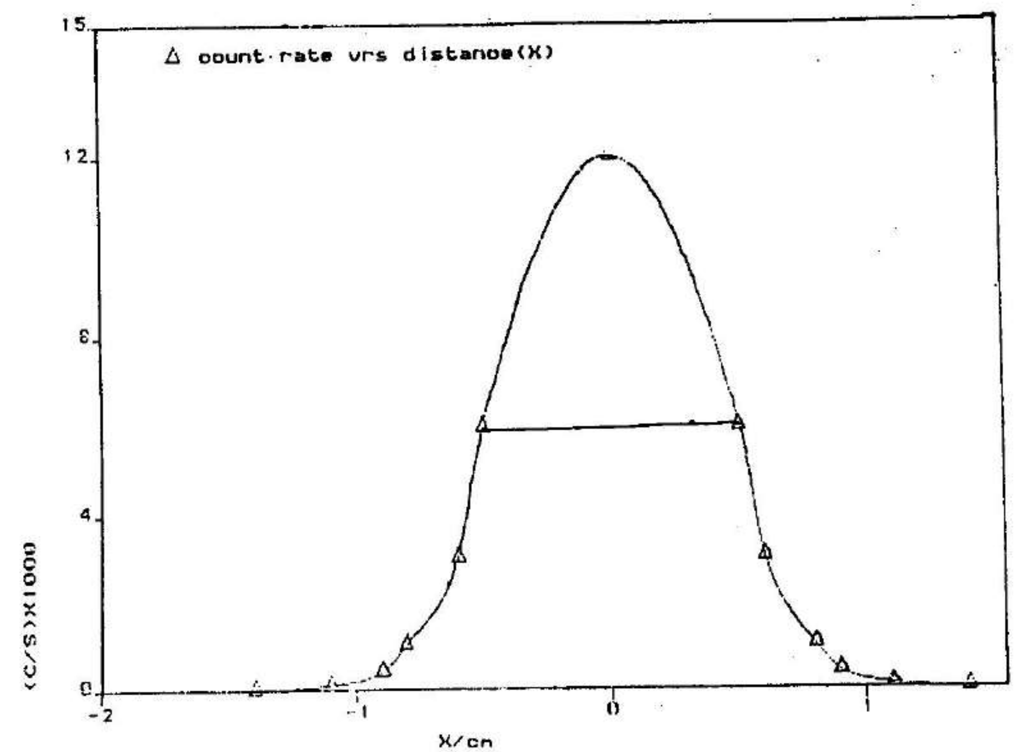

Fig. 2 LSF of TC - 99M Line Source
For Collimator F272 a134

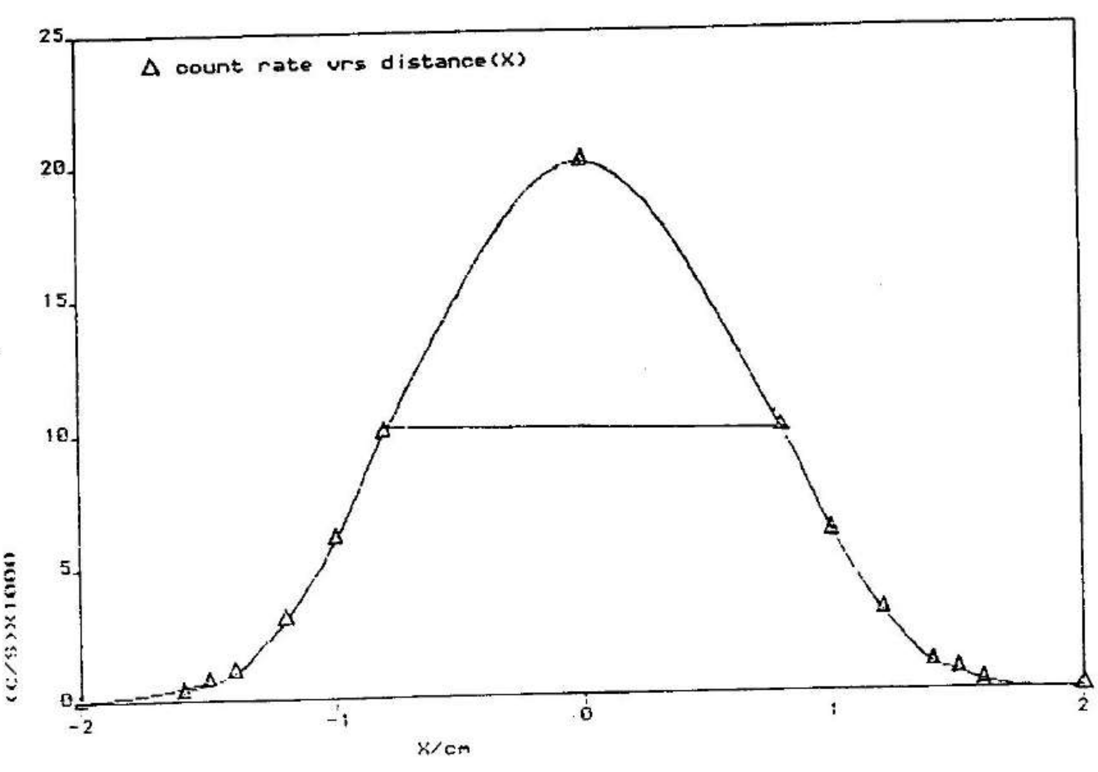

Fig. 3 LSF of TC - 99M Line Source
For Collimator F272 a135

counting rate to one-half the axial value [4].

The spatial resolution of the scintilant M800 scanner was evaluated with Tc-99m line source, 24cm in length and 2.0mm in diameter. The activity of the source was 1.8MBq. The line source was placed on a horizontal bench.

At a window of 50keV and zero background subtraction, the field of view of the collimator was passed across the line source along a line perpendicular to it. At the focal distance of each collimator the count rate was obtained at regular distance x, across the source. A graph of the count rate as a function of the distance is the LSF for each of the collimators. The width of the curve at half its maximum is the FWHM of the collimator. In addition, the relative sensitivities of the collimators were calculated as the ratio of the count rates at their photopeaks.

Figures:2, 3, 4 and 5 show the line spread function of each collimator. The results are summarised in Table 1. For the low energy Tc-99m, both the F272 a137 and F272 a134 collimators offer the best resolution of 1.0cm FWHM each; however the former gave the least sensitivity. The F272 a136 collimator has the highest sensitivity but with a resolution of 1.4cm FWHM which is lower than the previous two collimators.

Modulation Transfer Function (MTF)

A more sophisticated way of defining collimator response as well as the performance of every component within the detector system is by the modulation transfer function [3, 5, 6].

For a detector passing over a line source there would be a series of maximum and minimum activities in the sources and collimator. The source and image modulation are defined as the signal to noise ratio of a sinusoidally varying source and image respectively. The modulation of the source activity Ms may be defined as:

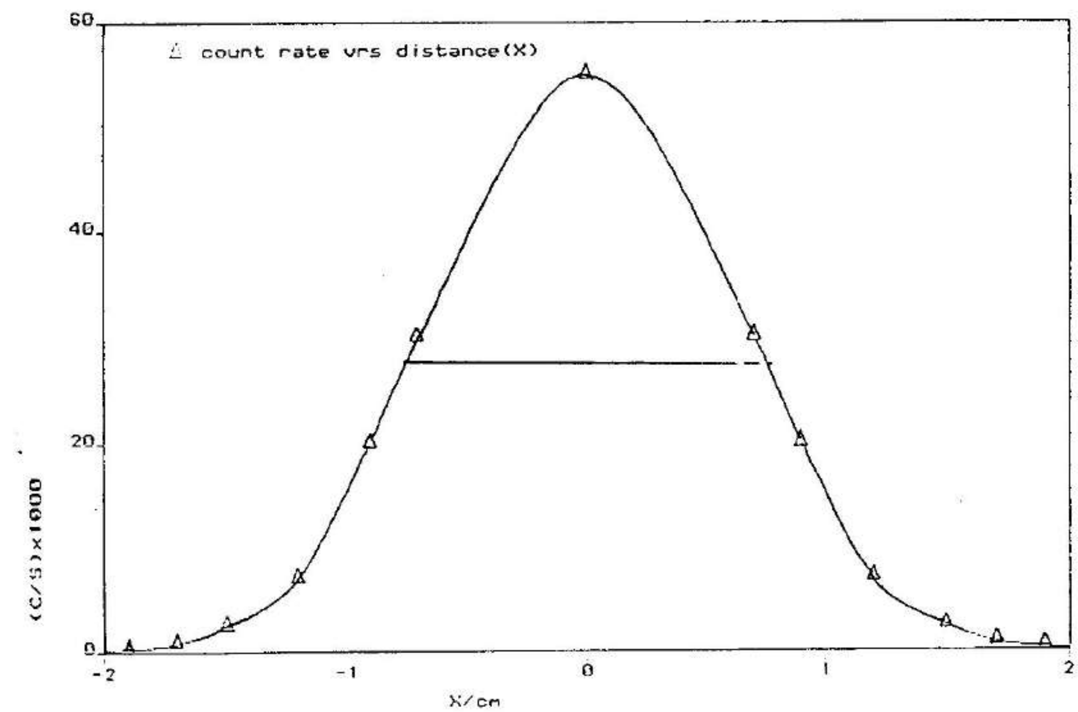

Fig.4 LSF of TC - 99M Line Source
For Collimator F272 a136

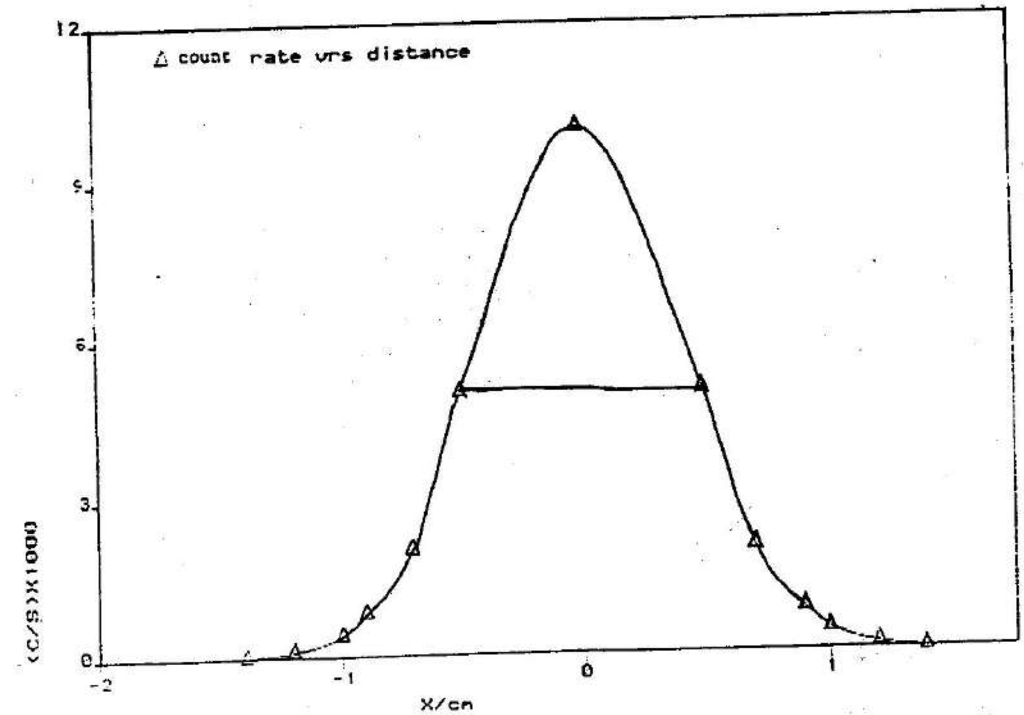

Fig.5 LSF of TC - 99M Line Source
For Collimator F272 a137

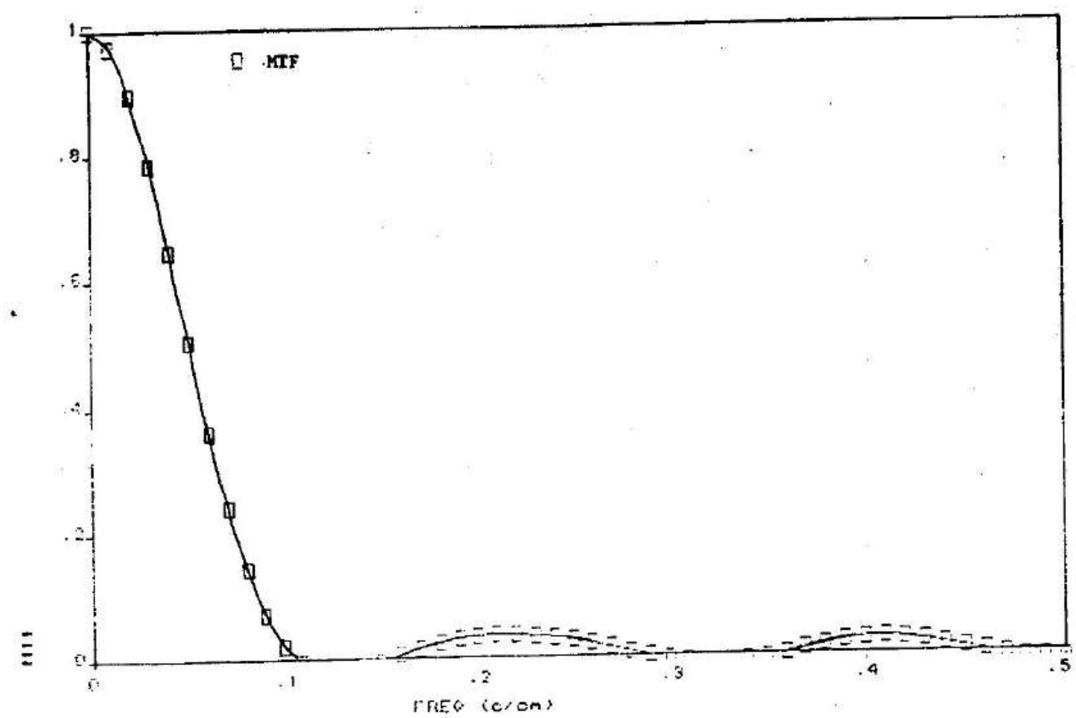

Fig.6 MTF for Collimator F272 a134

$$Ms = \frac{Smax\ -\ Smin}{Smax\ +\ Smin}$$

and of the detector system as:

$$Mc = \frac{Cmax - Cmin}{Cmas + Cmin}$$

where Si and Ci denote the activities in the source and detector respectively.
The modulation transfer function is:

$$MTF = \frac{Mc}{Ms}$$

More rigorously the MTF is the Fourlier transform of the LSF, L(x) and is expressed as:

$$MTF = \frac{L(x)\ \cos\ (2\ xfx)dx}{L(x)dx}$$

where f is the spatial frequency in cycles per millimeter, x the distance across the source [1. 4].

From the line spread function data obtained, a computer programme (obtainable from the Nuclear Medicine Unit, Korle Bu on request) was employed to obtain the MTF for each collimator.

Figures 6, 7, 8 and 9 indicate the variation of the MTF with frequency for each of the four collimators (Table 1). From the figures the resolution of all the collimators are poor, but F272 a134 and F272 a137 give the best resolution. The routinely used F272 a136 collimator gave a resolution only better than the F272 a135.

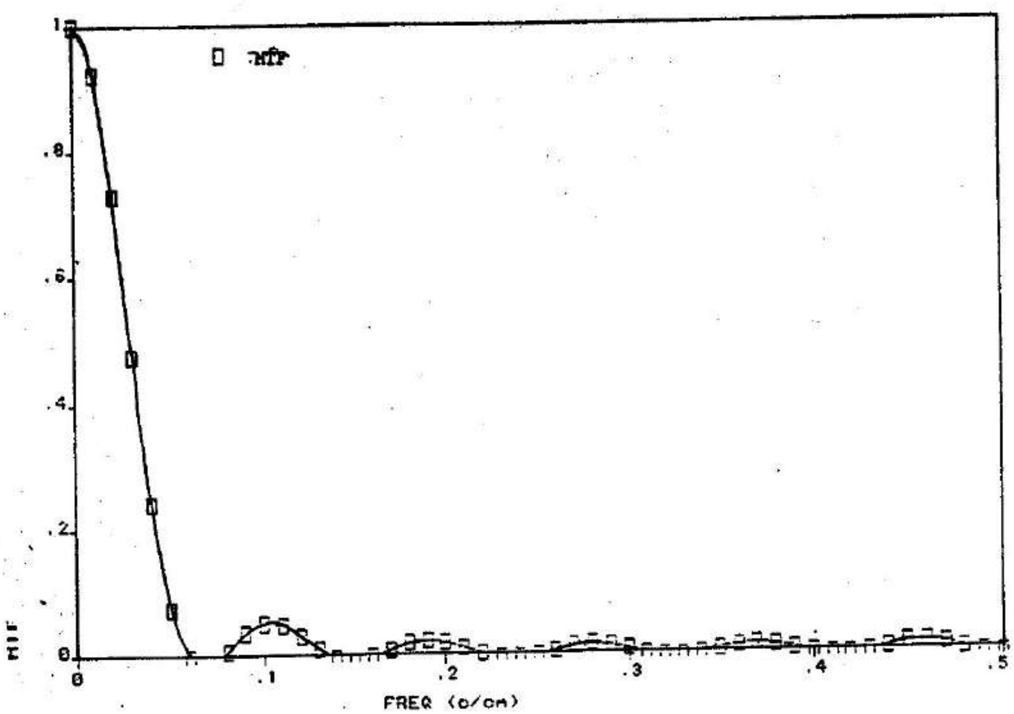

Fig.7 MTF for Collimator F272 a135

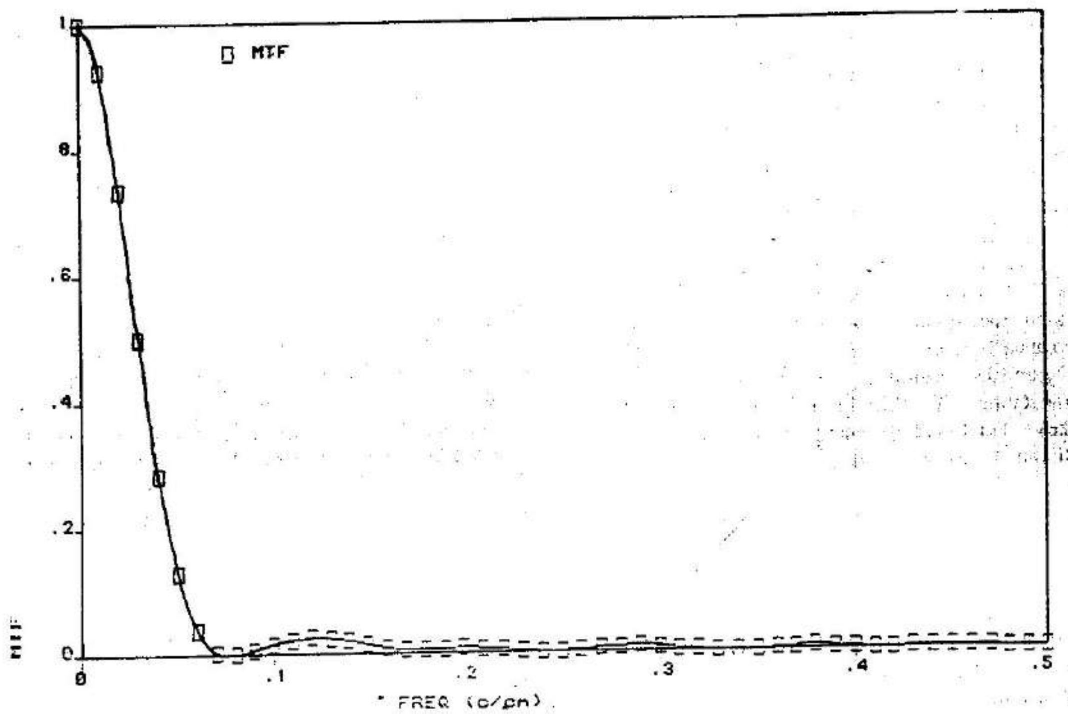

Fig.8 MTF for Collimator F272 a136

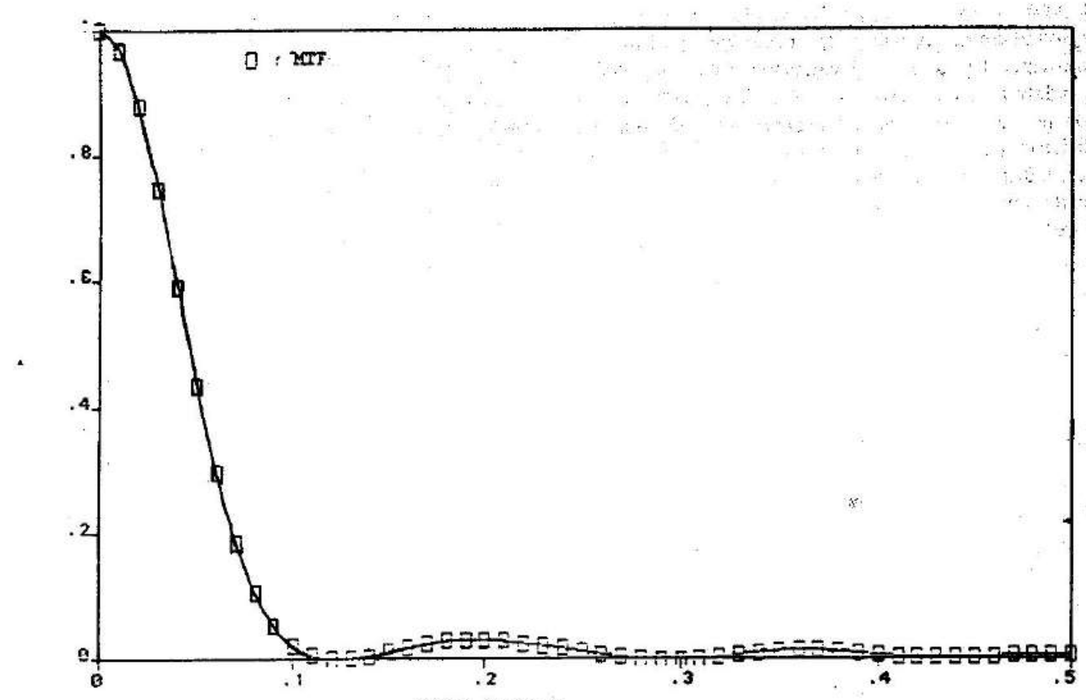

Fig. 9 MTF for Collimator F272 a137

Test of Energy Resolution

Energy resolution is a measure of the spread in amplitude of Voltage pulse representing the total absorption of the gamma rays of interest. It is usually stated as the percentage of the full width of the photopeak measured at half maximum (FWHM) [7]. It may be used to test the state of the working crystal.

A Cs-137 point source was used to measure the energy resolution of the spectrometer. The collimator was removed and the scanner head directed to view the source directly at a height of 10cm. At a window setting of 50keV, the pulse-height analyzer (PHA) control was decreased from 300keV to zero and the count rate recorded at each step.

Figure 10 gives the count-rate against the centre-of-window settings of the PHA. From the graph the FWHM is 60keV. For Cs-137 of energy 662keV the Energy Resolution of the crystal equals.

$$\frac{\text{FWHM} \times 100\%}{662} = 9.1\%$$

Discussion

A fundamental principle in the quality control of nuclear medicine instruments is that it should be undertaken as an integral part of the work of the nuclear medicine unit [7].

Regular quality control for a rectilinear scanner should cover its counting circuits, energy calibration, linearity of energy response, sensitivity, energy resolution, preset analyzer facilities, contrast enhancement, background subtraction and total performance [7]. These tests are carried out at various frequencies. The choice of tests and the frequencies with which they are carried out rest on the prevailing situations in the individual nuclear medicine unit and the status of the instrument. However what is indispensable is that appropriate individualized schedules and protocols should be adopted and strictly followed.

Record of tests performed need be kept as reference so that if the results of a particular subsequent test fail to fall within the specified limits of acceptability a decision could be taken whether to withdraw the instrument or use pending corrective measures. In the Korle-Bu nuclear medicine unit there are records on background subtraction, contrast enhancement and total performance. However there were no records on the other tests which are rather required to be performed in collaboration with the maintenance staff. These other tests were considered in this work.

Tc-99m is the tracer used in the unit. However the fixed programmes of discrimination for this isotope are out of use. As a result the position for Tc-99m on any of the other two scales of 10 to 100keV and 100kev to 1MeV would be useful in using the scanner. The position of the Tc-99m was obtained in the test of linearity on only the scale of 100keV to 1Mev. This suggests a non-linear relationship between the photon energy and the centre of the discriminator needed to observe the photopeak. Such a system may be used provided it is calibrated using various radionuclides [4]. In a linear system, a direct correspondence exists between the photon energy and the window needed to observe the photopeak.

From the graphs of the MTF (Figs. 6, 7, 8, 9) the resolution of the four available collimators were poor. For a well resolved system the MTF is of value one over a wide range of frequencies [4., 6]. The F272 a136 is the routinely used collimator in the unit. Though it possessed the highest sensitivity (Table 1) its resolution is lower than F272 a134 and F272 a137. A high resolution collimator gives well defined boundaries of lesion [8,9] however it compromises with sensitivity. Since in scanning a compromise in these two factors is required, and moreover Tc-99m tracer offers high activity [2, 10], the F272 a134 collimator could be said to be a good substitute to the routinely used F272 a 136 and can better detect smaller defects in organs.

Table 1 Characteristics of Available Collimators.

Collimator Type	Energy Level (key)	No of Holes	Focal Distance(cm)	FWHM(cm)	Relative line source sensitivity at the focus (%)
F272 a134	≤140	85	8.0	1.0	21.8
F272 a135	≤140	55	12.5	1.6	36.3
F272 a136	≤140	37	9.0	1.4	100.0
F272 a137	≤140	163	13.0	1.0	18.1

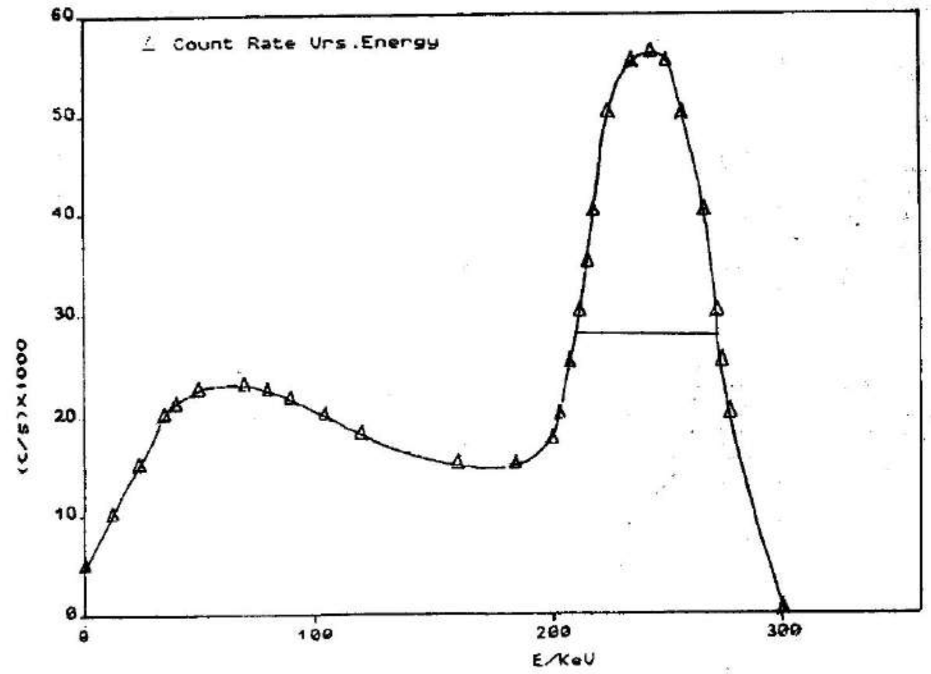

Fig.10 Test of Energy Resolution (:/FWHM)

From the energy resolution graph (Fig.10), there was a high background effect. At lower window settings it was impossible to obtain a wide range of readings. Generally, the width of the pulse-height analyzer window used in the test procedure influences the value of the %FWHM [7]. A typical value for %FWHM would be 9% for the crystal. A progressive increase may imply a deteriorating crystal or photomultiplier [7]. The existence of the photopeak and the 9.1%FWHM obtained confirm acceptable performance of the scintillation crystal.

CONCLUSION

The rectilinear scanner proved to be sufficiently robust to operate under the conditions experienced in the country. The performance of the scanner was evaluated by measuring the sensitivity and resolutions and determining the linearity of the energy response.

It was realized that though the routinely used collinator, F272 a136 offered the highest sensitivity, the F272 a134 gave the best resolution and the second best sensitivity. The presence of the Cs-137 photopeak on the energy resolution curve and the 9.1% FWHM obtained confirm the acceptance state of the NaI(T1) crystal. The position of the Tc-99m was obtained at 45±6keV on the scale of 100keV to 1MeV.

Though the working condition of the scanner falls within acceptable standard its slow speed and the increasing patient pressure coupled with the cost of obtaining the radiopharmaceutical call for its replacement by a more modern radionuclide scanning system such as the gamma camera.

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