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College on Medical Physics
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Scintillation Camera: N.E.M.A. Standards
Fundamentals of S.P.E.C.T.
S.P.E.C.T. : Quality Controls

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SCINTILLATION CAMERA: N.E.M.A. STANDARDS

FUNDAMENTALS OF S.P.E.C.T.

Single Photon Emission Computed Tomography

S.P.E.C.T.: QUALITY CONTROLS

CHAPTER 1

(some observations)

by

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N.E.M.A. STANDARDS

The N.E.M.A. standards for performance measurements of scintillation cameras have been developed to provide a uniform criterion for the measurement and reporting of scintillation camera performance parameters.

Procedures for quantitative measurements and reporting of performance parameters:

- Measurement techniques are chosen to be reproducibile, quantitative and accurate.
-Standards address single and multiple crystal scintillation cameras, exclude scanning and tomographic devices.
-All parameters are measured over the Useful Field of View (UFOV) of the camera (the collimated field of view) and Central Field Of View (CFOV). The CFOV is 75% of the diameter of the UFOV.
-Recommended instrumentation includes a computer based two parameters multichannel analyzer system with 1024x16 measurements resolution.
-Additionally,several phantoms and radionuclides are required.

INTRINSIC SPATIAL RESOLUTION

DEFINITION

Intrinsic means the basic scintillation camera without variables such as collimators which may change its inherent characteristics.

Spatial resolution is a parameter of a scintillation camera which characterizes its ability to accurately determine the original location of a gamma ray on an X-Y plane.

STANDARD

Intrinsic spatial resolution should be measured in both the X and Y directions and expressed as full width at half maximum (FWHM) and full width at tenth maximum (FWTM) of the line spread function measured in mm.

FREQUENCY OF TEST

At installation or after technical repairing or at least 3-4 times per year.

INTRINSIC ENERGY RESOLUTION

DEFINITION

Intrinsic energy resolution is a parameter of scintillation camera which characterizes its ability to accurately identify the photopeak events. This parameter in a scintillation camera determines its ability to distinguish between primary gamma events and scattered events. This test is intrinsic and done without a collimator.

STANDARD

Intrinsic energy resolution should be expressed as the ratio of photopeak full width at half maximum to photopeak energy expressed as percentage.

FREQUENCY OF TEST

At the installation or after technical repairing or at least 3-4 times per year.

INTRINSIC FLOOD FIELD UNIFORMITY

DEFINITION

Intrinsic flood field uniformity is a parameter of a scintillation camera which characterizes the variability of observed count with a homogeneous flux.

STANDARD

Intrinsic flood field uniformity should be expressed as "INTEGRAL UNIFORMITY" (a maximum deviation) and "DIFFERENTIAL UNIFORMITY" (a maximum rate of change over specified distance). Both should be measured for the UFOV and the CFOV.

In addition point source sensitivity variations should be expressed as a percentage variation.

In field uniformity correction devices are employed all measurements should be consistently performed with these devices on or off and the results so indicated.

FREQUENCY OF TEST

This test should be checked monthly and a daily visual test should be done using flood source.

INTRINSIC SPATIAL LINEARITY

DEFINITION

Spatial linearity is a parameter of a scintillation camera which characterizes the amount of positional distortion caused by the camera with respect to incident gamma events entering the detector.

STANDARD

Intrinsic spatial differential linearity and absolute spatial linearity in both X and Y directions should be measured. Differential linearity (expressed in millimeters) is the standard deviation of line spread function peak separations in the CFOV and UFOV using the intrinsic spatial resolution test pattern. Absolute linearity should be measured from the same test pattern data and should be expressed as the maximum amount of spatial displacement measured in the CFOV and UFOV.

REPORT

Absolute linearity: Maximum displacement of peak locations from ideal grid (X and Y) for CFOV and UFOV, expressed in millimeters.

Differential linearity: Standard deviation (X and Y) of peak separations for CFOV and UFOV, expressed in millimeters.

MULTIPLE WINDOW SPATIAL REGISTRATION

DEFINITION

Multiple window spatial registration is a parameter of cameras which characterizes positional deviations in the image at different energies.

STANDARD

The spatial registration of the images from each of the camera's windows should be measured for a collimated point source reported as the larger of the X and Y measurements, in millimeters.

REPORT

Maximum displacement in millimeters.

INTRINSIC COUNT RATE

DEFINITION

Count rate performance characterizes a scintillation camera's ability to accurately function at count rates which are near the maximum rate of camera operation.

STANDARD

Five parameters should be measured and reported:

REPORT

Input count rate for a 20 percent count loss, maximum count rate; and, as class standards, typical incident versus observed count rate curve, intrinsic spatial resolution at 75000 cps (observed), and intrinsic flood field uniformity at 75000 cps (observed).

SYSTEMS SPATIAL RESOLUTION WITH AND WITHOUT SCATTER

DEFINITION

System spatial resolution with and without scatter is a parameter of a scintillation camera and collimator which characterizes its ability to accurately determine the original location of a gamma ray on an X-Y plane.

STANDARD

As a class standard, system spatial resolution with and without scatter should be measured in both the X and Y directions and expressed as full width at half maximum (FWHM) and full width at tenth maximum (FWTM) of the line spread function expressed in millimeters, with the collimator specified.

REPORT

FWHM and FWTM average in CFOV

SYSTEM SENSITIVITY

DEFINITION

System sensitivity is a parameter of a scintillation camera with its collimator in place, which characterizes its ability to efficiently detect incident gamma rays.

STANDARD

As a class standard, the system sensitivity should be measured for each collimator and reported in counts/(minute uCi). Counts are defined as interactions in the crystal that fall within the analyzer window; therefore field uniformity correction devices which alter the number of counts must be disabled.

REPORT

System sensitivity counts/(minute µCi) with a specific collimator and relative sensitivity for each collimator.

N.E.M.A. STANDARDS

TEST	FREQUENCY
INTRINSIC SPATIAL RESOLUTION	3-4 TIMES PER YEAR
INTRINSIC ENERGY RESOLUTION	3-4 TIMES PER YEAR
INTRINSIC FLOOD FIELD UNIFORMITY	MONTHLY (DAILY VISUAL)
INTRINSIC SPATIAL LINEARITY	3-4 TIMES PER YEAR
MULTIPLE WINDOW SPATIAL REGISTRATION	3-4 TIMES PER YEAR
INTRINSIC COUNT RATE	2 TIMES PER YEAR
SYSTEMS SPATIAL RESOLUTION WITH AND WITHOUT SCATTER	1 TIME PER YEAR
SYSTEM SENSITIVITY	1 TIME PER YEAR

S.P.E.C.T. Single photon emission computed tomography:

QUALITY CONTROLS

The imaging properties of the SPECT system are investigated with respect to various factors which might introduce artifacts in the images.

Some tests and quality controls to assess the initial conditions and the working performance of a SPECT system, are described.

N.E.M.A. tests should first be carried out to check the planar scintigraphic performance of the gamma camera.

TEST TO EVALUATE THE PERFORMANCE OF SPECT AND THE CORRECT CHECK FREQUENCY OF INVESTIGATED PARAMETERS

TEST	FREQUENCY
STABILITY OF PHOTOELECTRIC PEAK DURING ROTATION	MONTHLY
SPATIAL UNIFORMITY	MONTHLY
SPATIAL RESOLUTION	MONTHLY
ALIGNMENT TO THE AXIS OF ROTATION	MONTHLY
SENSITIVITY	6_MONTHLY
IMAGE NOISE	AT INSTALLATION OR AFTER TECHNICAL REPAIRING
MTF FOR LINE SOURCE	

For a good Quality Assurance Program it is necessary to use a "QUALITY CONTROL REGISTER" for each gamma camera where you have to note:

1) TEST PERFORMANCE
   a) Date of test execution
   b) Aim of test
   c) Source and activity
   d) Number of counts collected
   e) Acquisition frequency of counts
2) RESULTS AND NOTES
3) COPY OF TECHNICAL REPAIRS UNDERTAKEN BY THE FIRM AND PRECAUTION

<u>TEST PERFORMANCE</u>

1) STABILITY OF THE DETECTOR

<u>PURPOSE</u>

The rotating procedure used in ECT introduces different disturbances from those occurring in regular use of the gamma camera.

The change amplification of the photomultiplier tubes or the optical transmission of light might be influenced by the rotation and this may result in instability of signal output.

The constancy of the total absorption peak of Tc99m is examined during the camera rotation.

This test is executed after checking the stability of the detector in planar acquisition.

<u>Radioactive source</u>

A small bottle of Tc99m solution of activity of the order of about a few hundred kBq is used.

<u>Data acquisition</u>

The peak position should be observed with the gamma camera at different acquisition angles (for example 0,45,90,135,180,225,270,315°).

<u>Data processing</u>

For each spectrum peak position and FWHM (Full Width at Half Maximum) shold be noted. The spectral shift shouldbe very slight.

2) SPATIAL UNIFORMITY

Radioactive source

A 20 cm diameter cylindrical plexiglass container is useful as phantom.

The central axis of the phantom is aligned with the ECT axis of rotation.

It is filled with Tc99m aqueous solution whose activity is nearly the same as the human organ activity.

Data acquisition

Acquisition parameters should be the same that are used for clinical tests: acquisition rate, frame size, angular step, ect.

Data processing

The tomographic sections are more sensitive to uniformity artifacts than are the conventional views.

The size of the uniformity artifacts is determined from flood field studies. (Choose a profile on a tomographic central section and process to have integral and differential uniformity).

Owing to non uniformity the artifacts influence the whole image of tomographic section.

3) SPATIAL RESOLUTION

Radioactive source

A cylindrical plexiglass phantom is used with inner plexiglass rods of various diameters: 20, 25, 15, 12, 10 mm.

Data acquisition

As for the uniformity test, fill the phantom with Tc99m aqueous solution and position it at the center of the field of view, the axis aligned with the axis of rotation of the system.

Imaging acquisition is taken using the previous parameters.

Data processing

At the moment we are only able to evaluate spatial resolution by visual examination of the image.

We can define a "GOOD SYSTEM" as one where the 12 mm rod is resolved.

4) ALIGNMENT TO THE AXIS OF ROTATION

Purpose

The reconstrucion algorithm assumes a direct relationship between the projections and the tomographic plane. When an axially rotating detector device is used, the axis of rotation is taken as the origin of the tomographic plane; the center of each projection should therefore be aligned with the same axis.

Radioactive source

A spot source is used (for example a syringe).

Data acquisition

The source should be positioned at any point in the field of view. Two planar acquisitions should be taken: the first at 0° position, the second at 180°.

Data processing

Non linearity in the field of view of the gamma camera might contribute to misalignements between the axis. The positions of the line sources are determined by analysing the count profiles in narrow slices across the two images. From the positional differences so obtained at 0° and 180°, the misalignements of the axis of rotation with the center of the matrix at various position can be calculated.

5) SENSITIVITY

Purpose

Sensitivity is determined by analysing the number of events registered per unit of time and unit of radioactivity emitted from a uniform phantom, filled with a uniform aqueous solution of Tc99m.

Radioactive source

The same phantom as used for uniformity test.

Data acquisition

Use data collected during "SPATIAL UNIFOMITY TEST"

Data processing

The volume sensitivity S_V is calculated as follows:

$$S_V = \frac{N_{tot}\ V}{A\ \ T}$$

where N_{tot} is the total number of events registered during an effective time T, A is the radioactivity in the phantom, corrected for radioactive decay and V is the volume of the phantom.

The effective time T is defined as the time for the acquisition only and does not include the time for rotation.

6) IMAGE NOISE

Purpose

Scintigraphic methods do, in general, suffer from a high level of noise, i.e. random uncertainty due to statistical photon counting. The mean density of registered events in a conventional view is often less than 10^3 : 10^4 counts per cm^2, yielding a Standard Deviation (SD) of about 2:5% in matrix cells of common size, 64x64. Noise appearing in reconstructed sections is more complex to predict because of the manipulation of the input data in the reconstruction operation.

Radioactive source

The uniformity phantom is filled with an aqueous solution of Tc99m.

Data acquisition

Data acquisition is performed at 64 angles in a series of studies where the acquisition time per angle is changed. For the reconstruction different filters are used.

Data processing

To quantify the magnitude of noise in transverse section we can use a semiempirical relationship between the random uncertainity (r.m.s.%), the total number of recorded events, the photon attenuation due to surrounding non source body material, the algorithm filter function.

$$\text{r.m.s.\%} = \frac{(1.8)^{3/2} \; R_{eff} \; R_s^{1/2} \; A_{body} \; C_{avg}}{2^{1/2} \; N_{tot}^{1/2}} \; (FF)^{1/2}$$

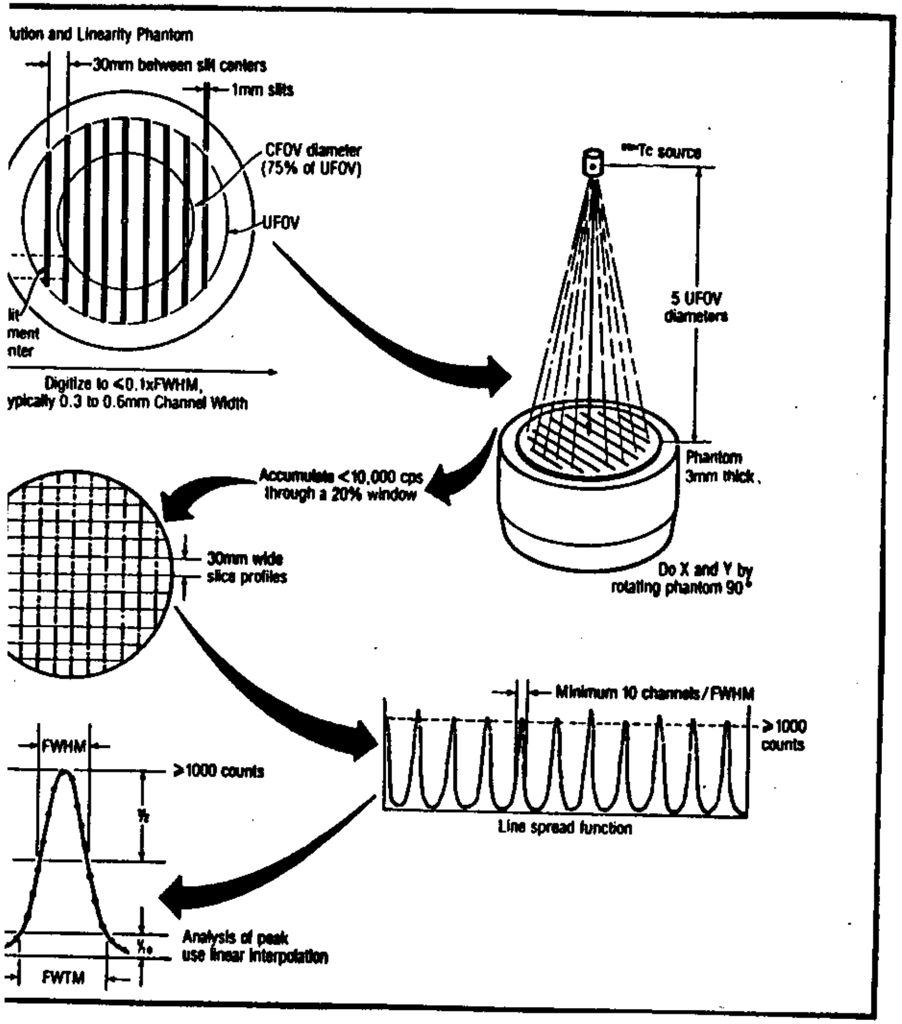
where R_{eff} is the effective radius of the source, R_s the actual source radius, A_{body} is the attenuation factor for surrounding non source body material, C_{avg} is the average attenuation correction factor for the center of the source, N_{tot} is the total number of events and FF is the algorithm filter factor and equals the integral of the square of the spatial frequency filter function.

The measured r.m.s.% noise level should be compared to the level calculated by previous equation.

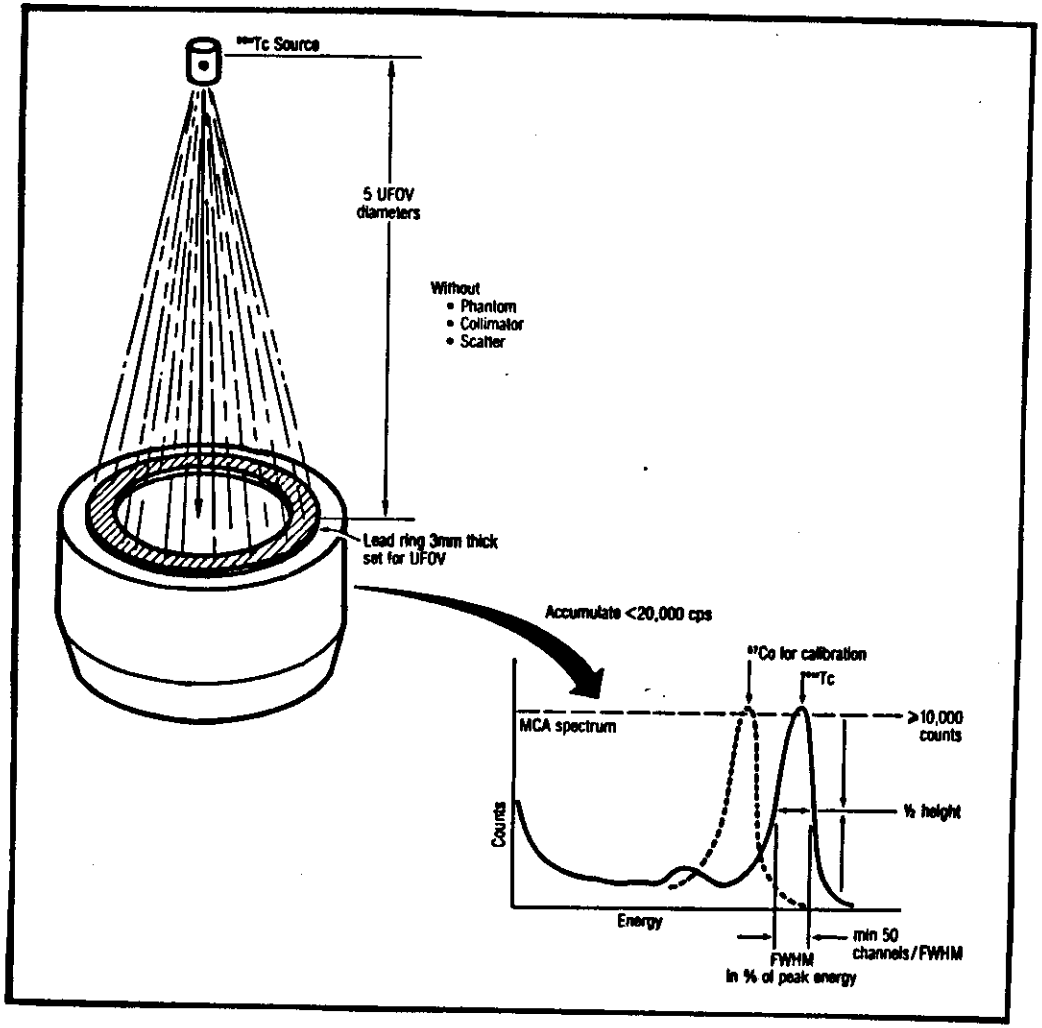
From a pratical point of view the importance of the r.m.s.% noise level is that it results in a quantitative method fordetermining that a SPECT system is properly functioning.

The correlation between predicted and measured r.m.s.% noise levels, together with resolution measurements, is adequate for assuring high quality, artifact free, reconstructed SPECT images.

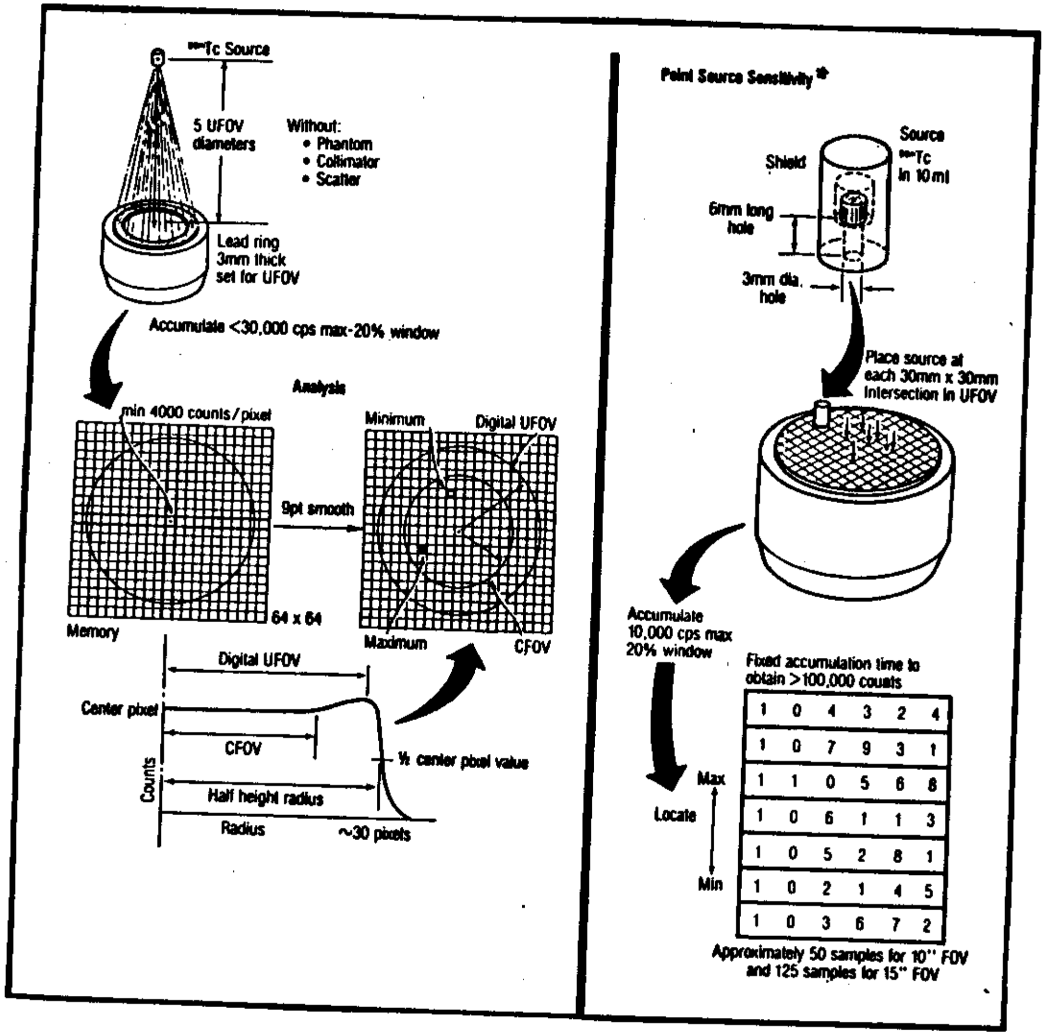
ntrinsic spatial resolution



2. Intrinsic energy resolution

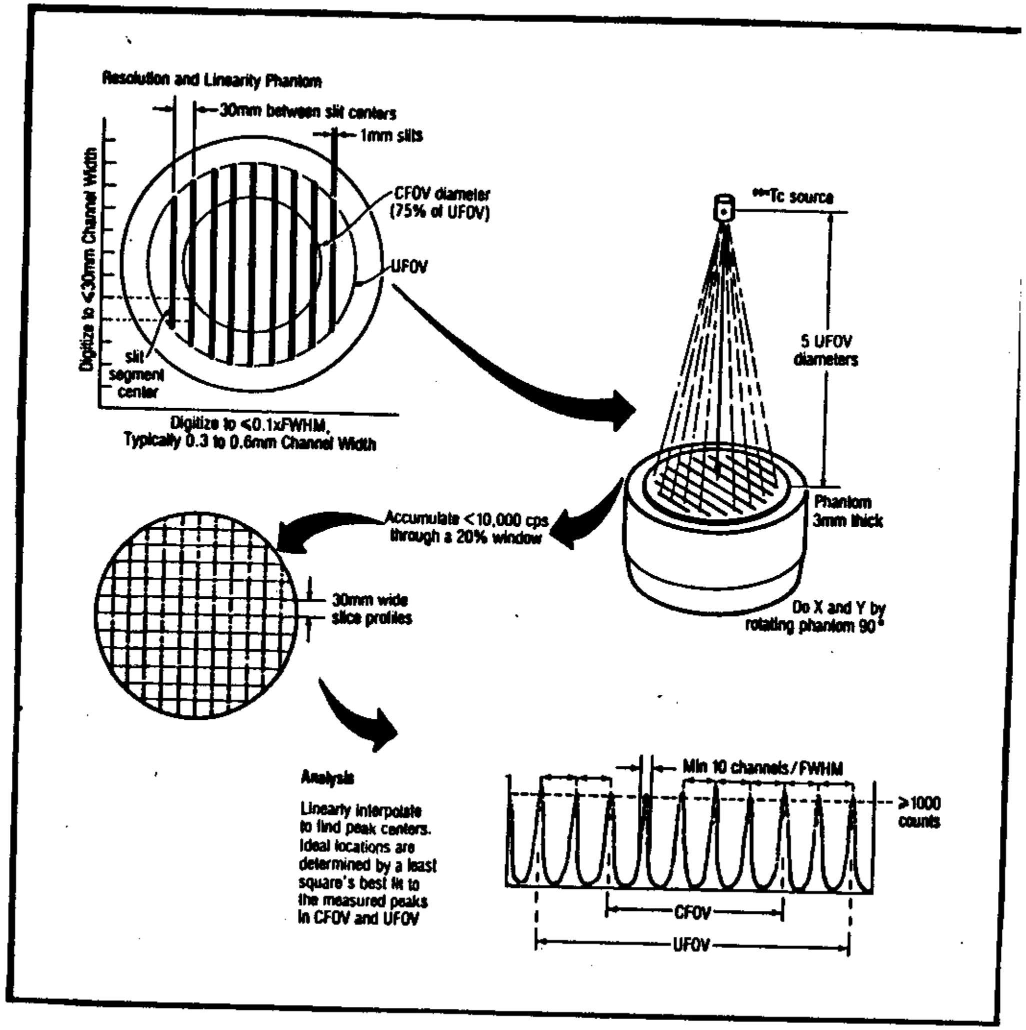


3. Intrinsic flood field uniformity

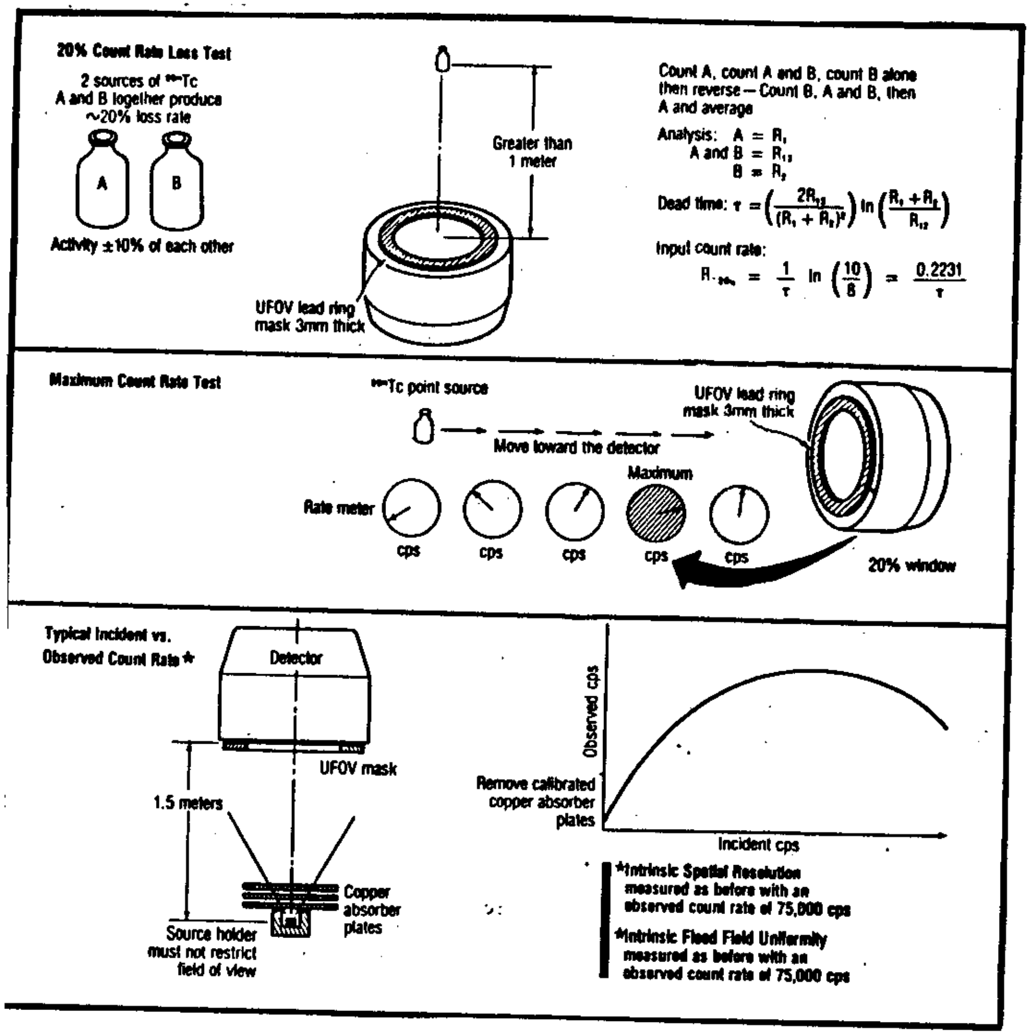


1	0	4	3	2	4
1	0	7	9	3	1
1	1	0	5	6	8
1	0	6	1	1	3
1	0	5	2	8	1
1	0	2	1	4	5
1	0	3	6	7	2

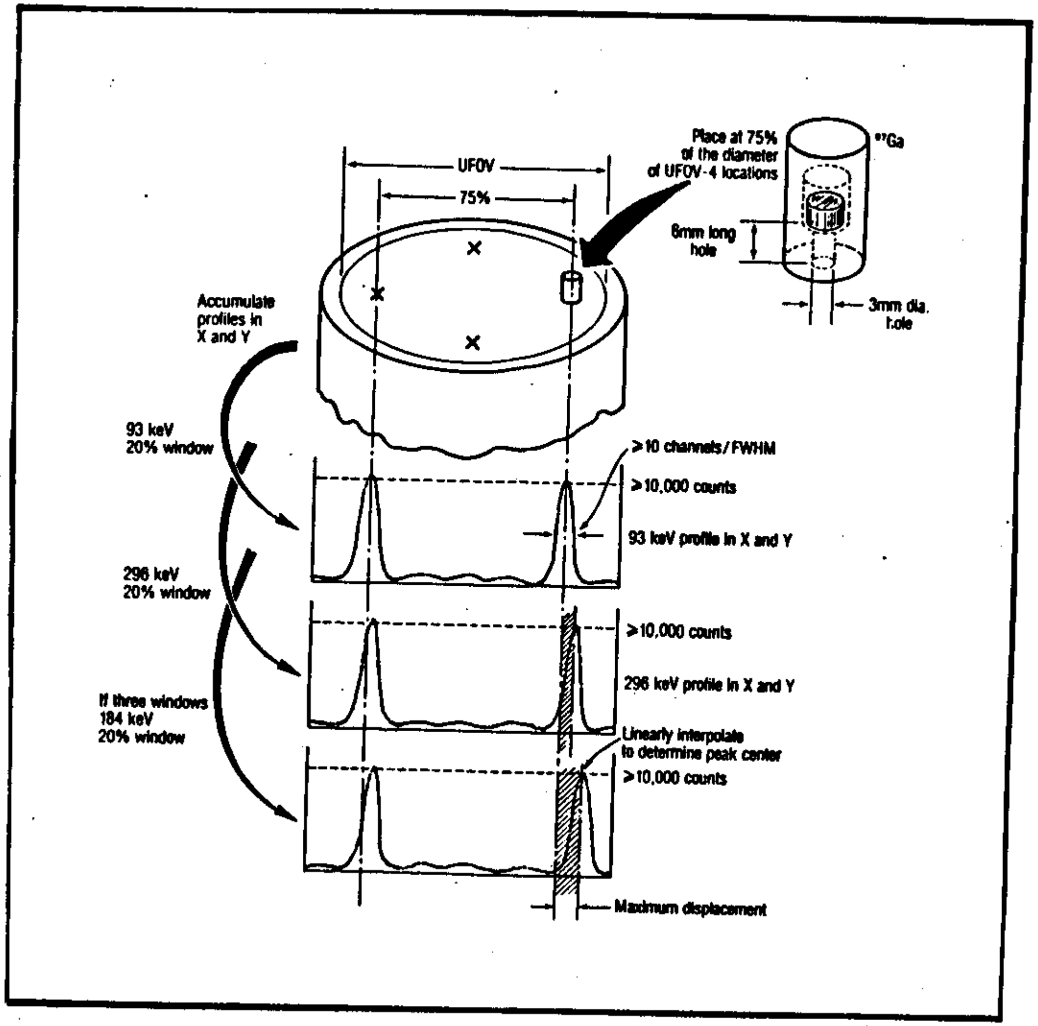
4. Intrinsic spatial linearity



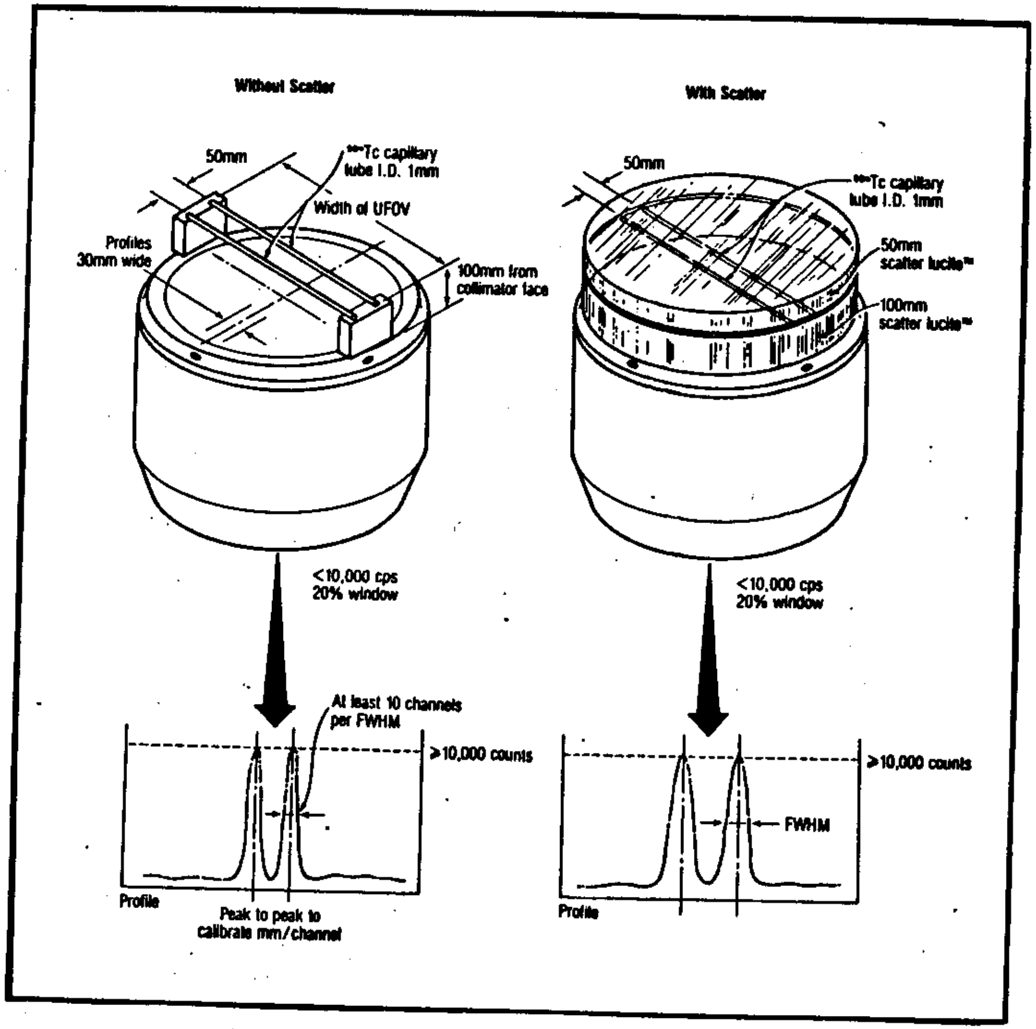
5. Intrinsic count rate performance



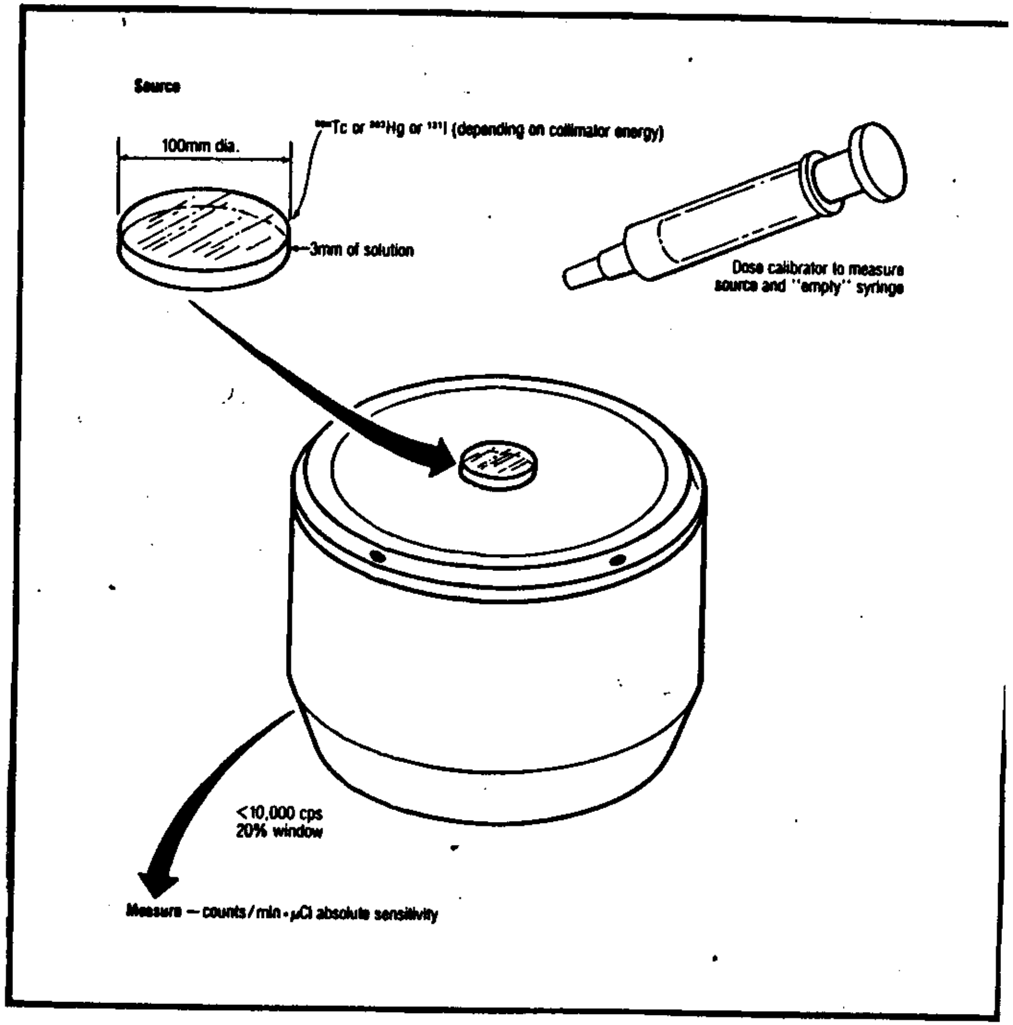
6. Multiple window spatial registration



7. Systems spatial resolution with and without scatter



8. System sensitivity



CHAPTER 2

FUNDAMENTALS OF SPECT

Single Photon Emission Computed Tomography

Single Photon Emission Computed Tomography (SPECT or ECT) has become an important diagnostic tool in Nuclear Medicine.

It provides better spatial information about the distribution of a radionuclide in an organ and, for many applications, improves lesion detection compared to conventional planar imaging.

Before the development of the ECT technique, the three-dimensional distribution pattern of radionuclides in the body could only be obtained by annihilation coincidence detection, using PET scanner. The PET technique, however, is limited to the study of positron emitting radiotracers.

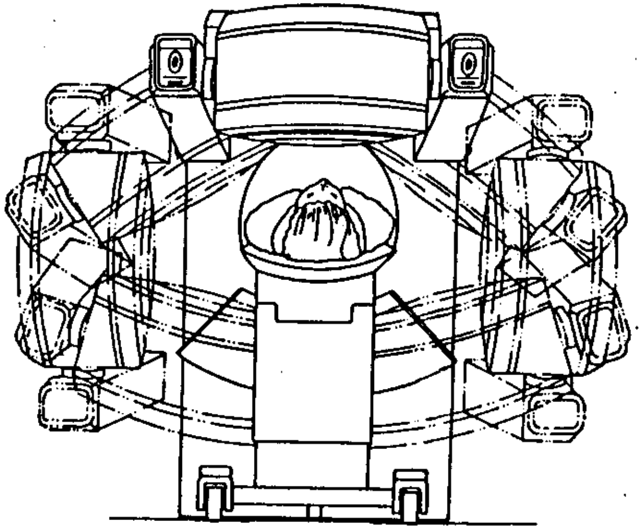


Fig. 1: ECT rotational movement.

THREE DIMENSIONAL DATA ACQUISITION

The ECT technique is an application of the principles of computerized tomography to conventional scintigraphy.
for ECT data acquisition the gamma camera accurately rotates around the patient in an orbit or half orbit and acquires a sequence of up to 180 planar images. (fig. 1)

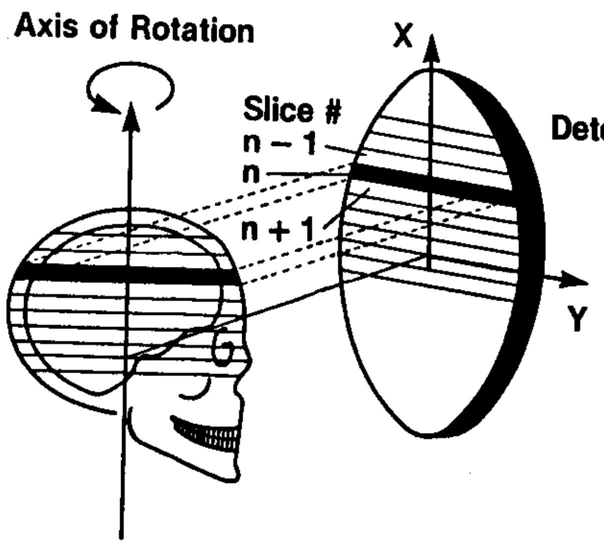


Fig. 2

Each planar image provides projection profiles for multiple slices. To obtain an ECT image, the detector head is rotated around an axis plotted through the body (fig. 2), while measurements are taken at different angles of rotation.
these measurements yeld a series of two dimensional or planar images, i;e. conventional scintigrams, that correspond to the distribution of the radioisotope in the body.
Consequently, rotational SPECT does not result in one single slice image but in a trhee dimensional data set.

The ECT image is reconstructed using the filtered back projection method.

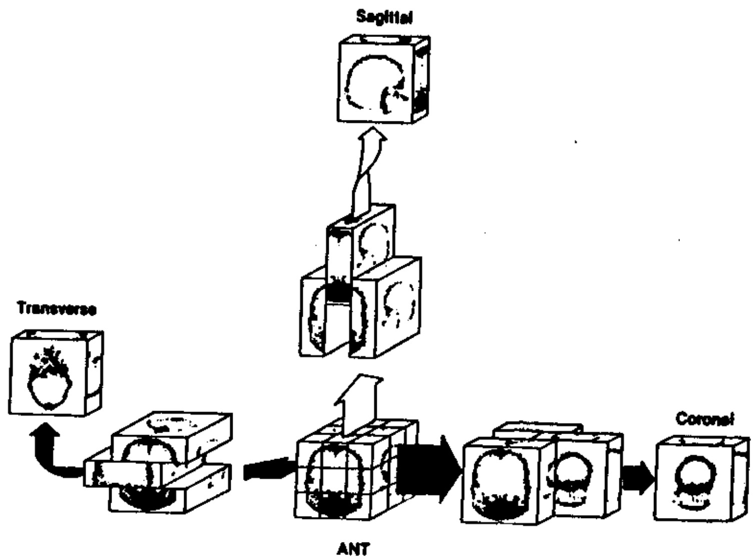


Fig. 3

SPECT IMAGE ORIENTATION

From the acquired projection images a set of transverse slice images is reconstructed.

the SPECT image data can be reorganized into saggital, coronal or oblique slices.

The display of ECT images in varius orientations reflects the true three dimensional distribution of activity.

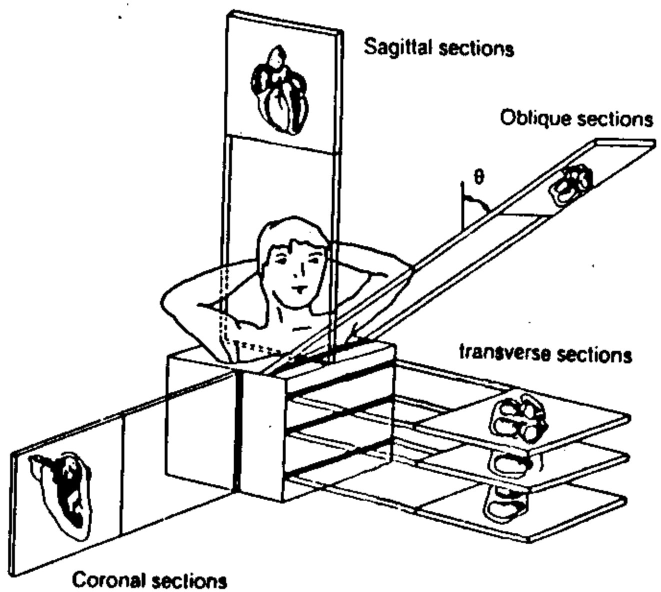


Fig. 4: Transaxial, sagittal, coronal, and oblique planes through the heart.

The reconstructed ECT image is initially presented in the form of images transaxial (transverse) slice of the body. (fig; 4)

Depending on the system's software, however, this transaxial data may be used to mathematically generate views of different orientation, that will enhance and extend the diagnostic potential of the image.

Figure 4 illustrates graphically the type of image that will be obtained of the human heart if viewed from all possible orientations.

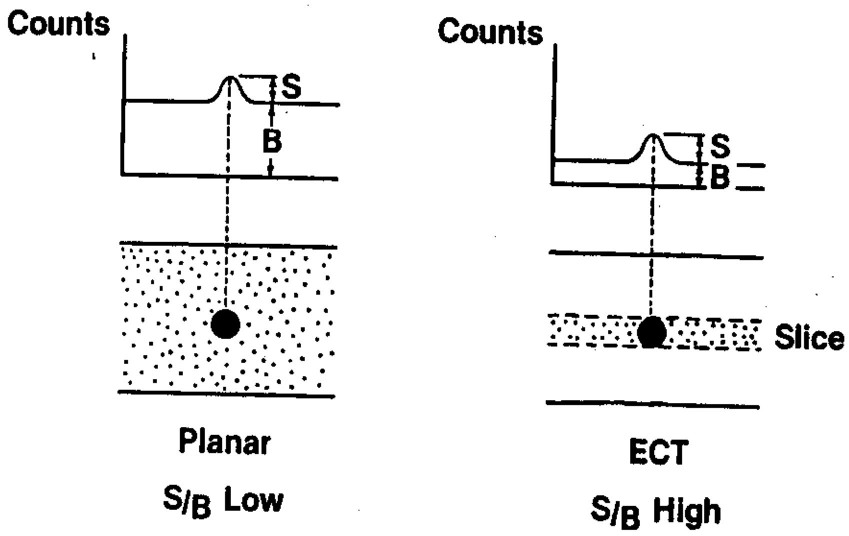


Fig. 5

Improved image contrast

The ability of ECT to depict the three dimensional distribution pattern of radionuclide whiting the body is far its primary advantage over conventional scintigraphy, but by no means the only one.

In conventional planar images, contrast is usually low because the source activity is superimposed with background activity. Spect yelds slice images with virtually no background activity.

The result is increased signal to background ratio and better detection of small lesion. (fig. 5)

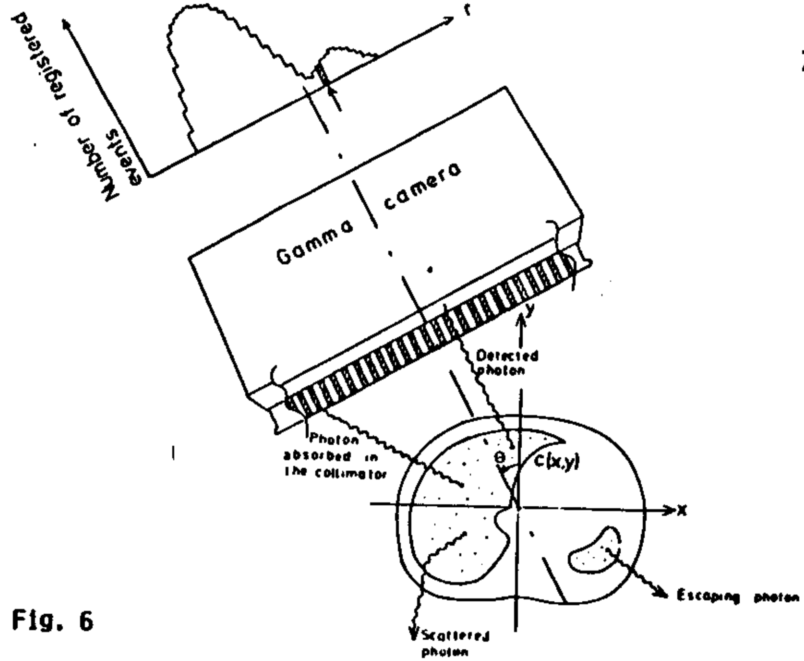


Fig. 6

THE RECONSTRUCTION ALGORITHM (BACK PROJECTION)

The reconstruction algorithm constitutes the mathematical link between the measured data and the tomographic image.

Most SPECT reconstruction software utilizes back projection methods.

Projection images of the object are acquired from several angles around the object. (fig. 6).

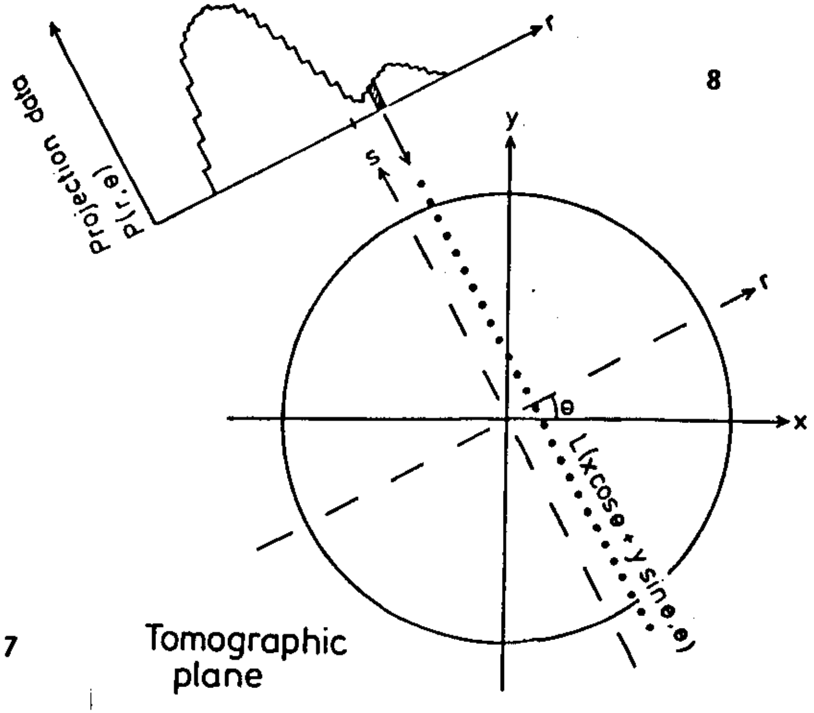


Fig. 7

BACK PROJECTION & TOMOGRAPHIC PLANE

A stationary X ; Y coordinate system defines the tomographic plane with reference tothe body.

The projections are then BACK PROJECTED slice by slice into an image matrix which represents a reconstructed slice image. Fig.8

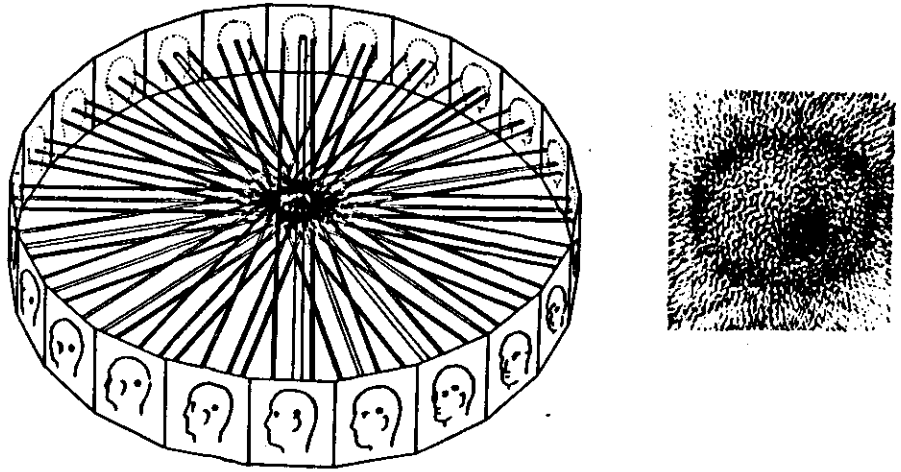


Fig. 8

BACK PROJECTION

The basic concept of reconstruction tomography involves taking data from many two dimensional views (taken at slightly different angles) and back projecting them, by this means a three dimensional distribution of activity in the subject can be obtained.

On the right, a detailed view of the reconstruction image shows the contribution of each projection to the final image.

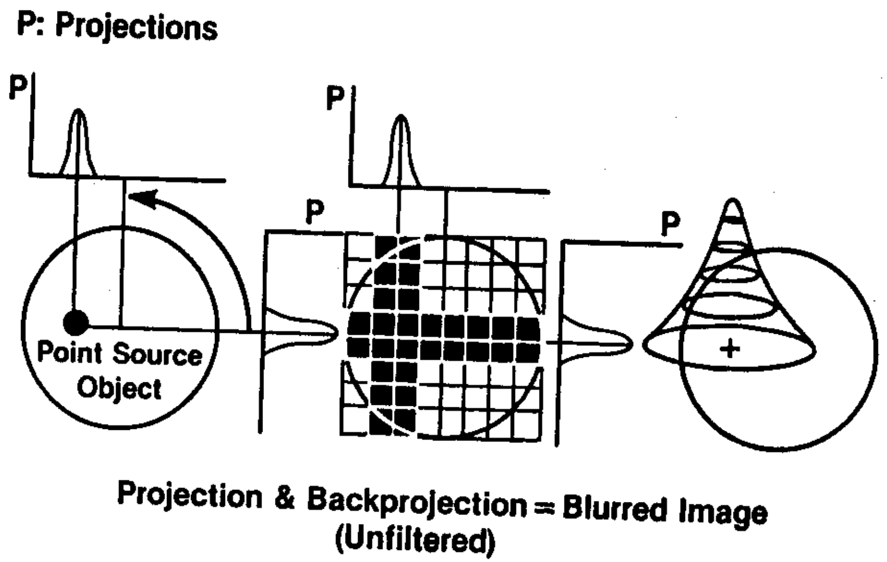


Fig. 9

As the projection data do not have any information about the depth of the source, the number of counts measured in each projection is equally distributed over the depth.

The result is a reconstructed image of the source which gives the correct location, but is intolerably blurred unless appropriate filters are applied.

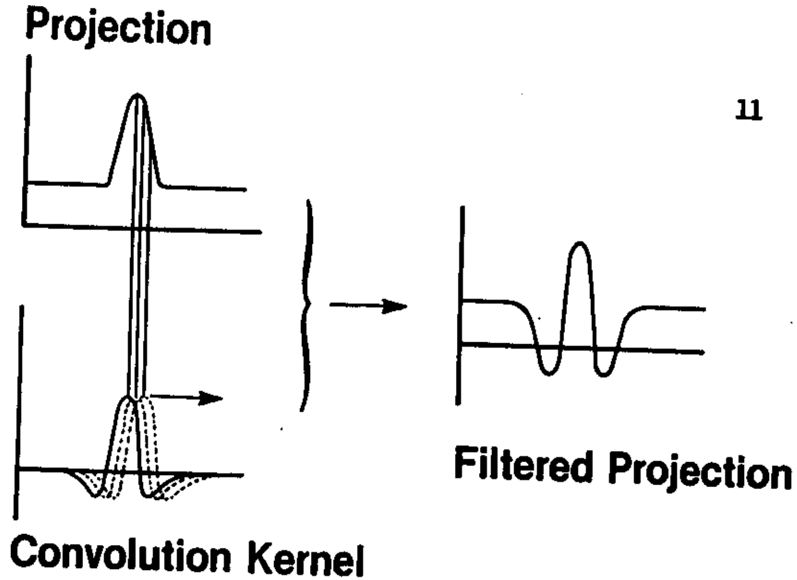


Fig. 10

FILTERED BACK PROJECTION

Rather than back projecting the unprocessed image data, the projections are first filtered, or convolved.
This results in nonblurred, sharp images.

Each point in the filtered projection is calculated from all the values in the original projection weighted by a function which is called the "convolution kernel" or "filter function".

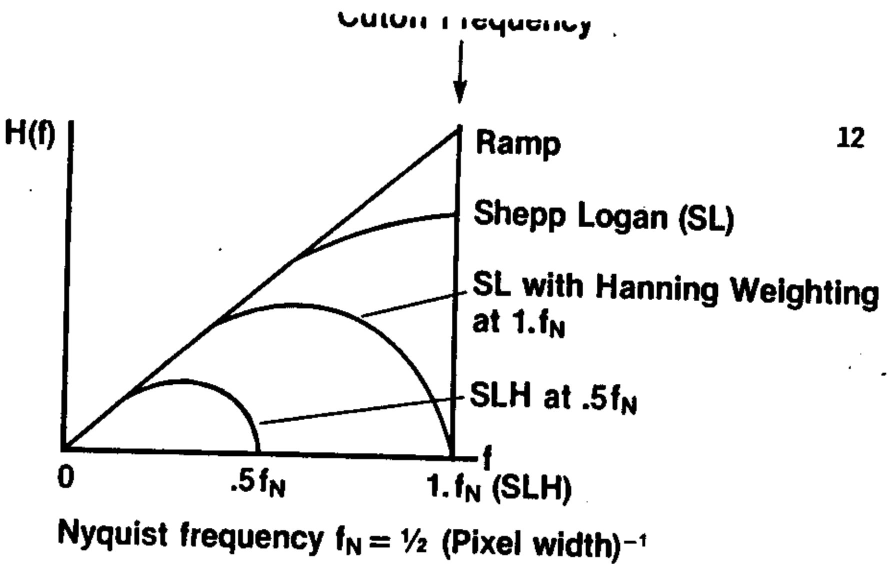


Fig. 11

FILTER FUNCTION

In SPECT, the operator selects the appropriate filter function dependent upon the number of counts expected in the study. The figure demonstrates four examples of filter function represented in the spatial frequency domain.

The cut off frequencies are 1.0 and 0.5 Nyquist, respectively. The Nyquist frequency is half the inverse pixel width and reflects the image matrix resolution.
The RAMP filter is the sharpest and gives the best spatial resolution, but emphasizes noise and is therefore used only in count abundant studies.
The SHEPP LOGAN and HANNING filters are the smoothest and are recommanded for most clinical studies.

PHYSICAL PROPERTIES

There are some importants correction procedures which are important for superior ECT imaging.

The imaging properties of the SPECT were investigated with respect to various factors which might introduce artifacts in the images.
Physical limitations in terms of :

spatial resolution
sensitivity
uniformity correction
center of rotation (mechanical and electrical)
thickness of sections
image noise
have been studied.

These factors alone will not sufficiently describe all physical properties of the SPECT but they will provide an interpretor with important information about limitations and origins of artifacts for the extraction of relevant clinical information from the images obtained.