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Performance Measurements of Scintillation Cameras

NEMA

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NEMA Standards Publication NU 1-1994

PERFORMANCE MEASUREMENTS OF SCINTILLATION CAMERAS

Published by

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Foreword

User input has been considered in the development of this Standards Publication. The Standards Publication was developed by the Nuclear Section of the National Electrical Manufacturers Association, which will periodically review it for any revisions necessary to keep it up to date with advancing technology. Proposed or recommended revisions should be submitted to:

Vice President, Engineering Department
National Electrical Manufacturers Association
2101 L Street, N.W. Suite 300
Washington, D.C. 20037-1526

CAUTION: Persons using this measurement performance standard must be in compliance with all applicable federal and state regulations (Ref: NRC Regulatory Guide 10.8, *Guide for the Preparation of Applications for Medical Programs*) for the use, handling, and possession of radioactive material.

Purpose

The purpose of this Standards Publication is to provide a uniform criterion for the measurement and reporting of scintillation camera performance parameters by which a manufacturer may specify his device and, when doing so, reference NEMA Standards Publication No. NU 1-1994, *Performance Measurements of Scintillation Cameras*. This standard does not establish minimum performance levels.

Specific measurement equipment, as set forth herein, is required in order to accomplish the purpose of this standard, the uniform and accurate specification of performance characteristics.

Without this equipment, the measurements performed would be limited, inaccurate, non-quantitative, or too time consuming.

Scope

This Standards Publication establishes definitions, quantitative measurements of performance characteristics, and reporting techniques for the specificatior of the following scintillation camera parameters:

a. Intrinsic spatial resolution
b. Intrinsic spatial linearity
c. Intrinsic energy resolution
d. Intrinsic flood field uniformity
e. Intrinsic count rate performance
f. Multiple window spatial registration
g. System spatial resolution with and without scatter
h. System planar sensitivity
i. System volume sensitivity
j. System count rate performance with scatter
k. System flood field uniformity, multiple crystal cameras
l. System spatial linearity, multiple crystal cameras

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m. Reconstructed spatial resolution without scatter
n. Reconstructed spatial resolution with scatter
o. Reconstructed image uniformity
p. Whole body system spatial resolution
q. Detector shielding

Inclusion—Types of medical radionuclide imaging instruments included in this standard are:

a. Single detector, single crystal scintillation cameras
b. Single detector tomographic scintillation cameras
c. Multiple detector planar and tomographic scintillation cameras
d. Whole body scintillation camera devices
e. Multiple crystal scintillation cameras

Exclusions—All medical radionuclide imaging devices not included in the above.

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Section 1
REFERENCED PUBLICATIONS, DEFINITIONS, AND TEST EQUIPMENT

1.1 REFERENCES

International Electrotechnical Commission
3, rue de Varembe
Geneva, Switzerland

IEC Technical Publication 789
1990

Characteristics and Test Methods for Anger Type Gamma Cameras

Nuclear Regulatory Commission
1717 H St., N.W.
Washington, DC 20006

NRC Regulatory Guide 10.8
January 1979

Guide for the Preparation of Applications for Medical Programs, Appendix D, Section 2, Methods for Calibration for Dose Calibrator

1.2 GENERAL DEFINITIONS

This Standards Publication is classified as NEMA Standard unless otherwise indicated and establishes definitions, quantitative measurement of performance characteristics and reporting techniques.

Absolute linearity: the amount of positional distortion or displacement of the X and Y coordinates over a field of view of the scintillation camera.

Energy window: range of gamma and x-ray energies which are to be accepted and processed. The window is expressed as a range of energies (e.g., 120–160 keV) or as a percentage of an expected peak energy (e.g., 20% of 140 keV). When expressed as percentage the peak energy must always be specified, and the window is always symmetrical about the peak energy value (e.g., 20% window at 140 keV is the same as a window from 126 to 154 keV).

Central Field of View (CFOV): the area defined by scaling all linear dimensions of the Useful Field of View (UFOV) by a factor of 75%.

Class Standard: a value (or set of values) which characterizes a specific parameter or is typical of a given model number or series of scintillation cameras. Class Standards are measured on a limited number of instruments of a given model.

Detector: that component of the scintillation camera which detects incident gamma radiation for the purpose of imaging and counting.

Differential linearity: the amount of positional distortion or displacement over a limited distance.

Differential uniformity: the amount of count density change per defined unit distance when the detector's incident gamma radiation is a homogeneous flux over the field of measurement.

Digital resolution: the size of the pixel used to sample analog data.

Energy resolution: a term used to characterize the ability of a gamma camera to distinguish between photons of different energies.

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Full Width at Half Maximum (FWHM): the measure of the spread of a point or line spread function measured between locations 50 percent down on each side from the peak amplitude.

Full Width at Tenth Maximum (FWTM): the measure of the spread of a point or line response function measured between locations 90 percent down on each side from the peak amplitude.

Integral uniformity: a measure of the maximum count density variation over a defined large area of the scintillation detector for a uniform input gamma flux to the Useful Field of View of the camera.

Input count rate: the rate of scintillation events that are accepted by the energy window and would be recorded as the observed count rate if there were no dead time in the system. At low counting rates (less than 4000 cps) the input count rate is assumed to be the same as the observed count rate because dead time losses are negligible.

Intrinsic: a term used to describe performance characteristics of a scintillation camera that exclude external variables which affect these specifications such as collimators or display devices.

Linear interpolation: refers to the method of calculating an intermediate value that lies on a straight line between two known values.

Linearity: the amount of positional distortion or displacement of the measured position of photons relative to the actual position where those detected photons entered the detector.

Observed count rate: the number of gamma rays per unit time recorded by the scintillation camera's counting electronics.

Performance standard: represents test measurement specifications that apply to, and must be met by, every scintillation camera covered by the specification.

Photopeak: the characteristic energy distribution resulting from the collection of total photon energy absorbed by the detector.

Pixel: a picture element used to store a value in a digital memory. It represents an area defined by dimensions in X and Y directions at a known position defined by X and Y coordinates.

Scatter: photons that have lost part of their energy due to interaction with a medium, such as water, plastic, or tissue.

Sensitivity: the observed count rate per unit of radioactivity.

Spatial resolution: a term which characterizes the scintillation camera's ability to accurately resolve spatially separated radioactive sources.

Spectrum: a plot of the number of detected gamma rays versus the measured energy of the gamma rays.

Standard deviation: a statistical index of the degree of variability within a distribution. In a normal distribution, 68 percent of the observations made will be within plus or minus one standard deviation from the mean value.

System: a term used to refer to the performance of the camera detector as it would be used in a clinical environment including components such as a collimator and supporting gantry.

Test pattern: a lead pattern that projects a known shadow of itself when illuminated by gamma rays from a specified source; used as controlled input for measurement of scintillation camera parameters.

Useful Field of View (UFOV): the area of the detector which is used for imaging gamma rays and x-rays. It is defined by a dimensioned figure supplied by the manufacturer.

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1.3 TEST EQUIPMENT, CONDITIONS AND RESULTS

1.3.1 Source Holders and Test Fixtures

A number of different source holders is required for the performance of the procedures. Each source holder is described in the individual procedure for which it is required. Manufacturing tolerances and materials of source holders are often critical in ensuring precise and reproducible measurements. Care has been taken to make the source holder's designs as simple as possible, consistent with the requirements for precision and accuracy in the measurement procedures.

All dimensional tolerances shall be •10% unless otherwise specified.

1.3.2 Radiation Sources

A variety of different shapes and activities of radiation sources is required. The majority are Tc-99m. Co-57 can often be substituted for Tc-99m as indicated in individual procedures. Ga-67 is required to perform the Multiple Window Spatial Registration procedures.

Some procedures for multiple crystal cameras recommend the use of Am-241 point source. Generally, the procedures can also be performed with other radionuclides provided the radionuclide used is clearly reported with the test results. It should be noted that some of the sources listed here may require special licenses for possession.

1.3.3 Test Conditions

All tests shall be performed in a clinically consistent mode of operation with appropriate corrections applied: energy, linearity and uniformity corrections being employed, and normal count rate mode.

If field uniformity, energy, or linearity correction is employed, all measurement shall be consistently performed with these corrections on and the results so indicated. The energy windows utilized should also be specified.

Any additional tests, at variance with the above conditions or test parameters, shall be separately reported and the variances shall be clearly indicated.

If, for quality assurance or other purposes, the manufacturer employs radionuclides other than those prescribed by this standard, he shall demonstrate traceability between the radionuclide prescribed for the measurement and the radionuclide employed.

1.3.4 Reporting

Reported performance standard specifications shall be labeled as "worst case," "better than" and "not to exceed." Reported class standard specifications shall be labeled as "typical."

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Section 2
SINGLE CRYSTAL SCINTILLATION CAMERA TEST METHODS: PERFORMANCE STANDARDS

2.1 INTRINSIC SPATIAL RESOLUTION

Intrinsic spatial resolution shall be measured as a performance standard.

2.1.1 Test Conditions

The radionuclide employed for this test shall be Tc-99m. A source holder which shields the source from walls, ceilings and personnel without restricting the gamma flux from the source to the camera (as shown in Figure 2-1) shall be employed. The energy window shall be 20 percent centered on the photopeak.The count rate shall not exceed 20,000 cps through the energy window.

2.1.2 Test Equipment

The test pattern shall consist of a lead mask in closest possible proximity to the crystal, covering the entire UFOV with 1 millimeter wide parallel slits. Adjacent slits centers shall be 30 millimeters from each other (see Figure 2-2 which shows the geometry for rectangular field of view). The thickness of the mask shall be 3 millimeters for Tc-99m.

2.1.3 Measurement Procedure

The lead mask with the parallel slits shall be positioned on the camera detector with one of the slits centered perpendicular to the axis of measurement. The radionuclide shall be a point source centered at least five times the largest linear dimension of the UFOV above the lead mask with the parallel slits. The digital resolution perpendicular to the slits is recommended to be less than or equal to 0.1 FWHM. The digital resolution parallel to the slits shall correspond to a channel width less than or equal to 30 millimeters. At least 1,000 counts shall be collected in the peak channel of each line spread function measurement. Full Width at Half Maximum (FWHM) and Full Width at Tenth Maximum (FWTM) of the line spread function shall be measured.

2.1.4 Calculations and Analysis

If the digital resolution perpendicular to the slits is less than or equal to 0.1 FWHM, then the maximum value pixel is taken to be the peak value.

If the digital resolution perpendicular to the slits is more than 0.1 FWHM, a three point parabolic fit, using the peak point in each line spread function and its two nearest neighboring points respectively, shall be employed. The peak value shall be then determined from the largest value of this parabolic fit (see Figure 2-3).

The half maximum and tenth maximum locations shall be determined by linear interpolations from the nearest two neighboring points of the half peak value and the tenth peak value respectively, using the peak value in each line spread function curve as the maximum (see Figure 2-3).

The distance between adjoining peaks shall be averaged over the entire UFOV for determining the millimeters channel calibration factor. The calculated average distance shall correspond to the 30 mm distance between the slits. This calibration factor shall be used to convert the calculated values of FWHM and FWTM from units of channels to millimeters per channel. The value of FWHM and FWTM shall be calculated as the average of all such values for both axes, lying within the UFOV and CFOV respectively. The calculated values shall not be corrected for background or slit width.

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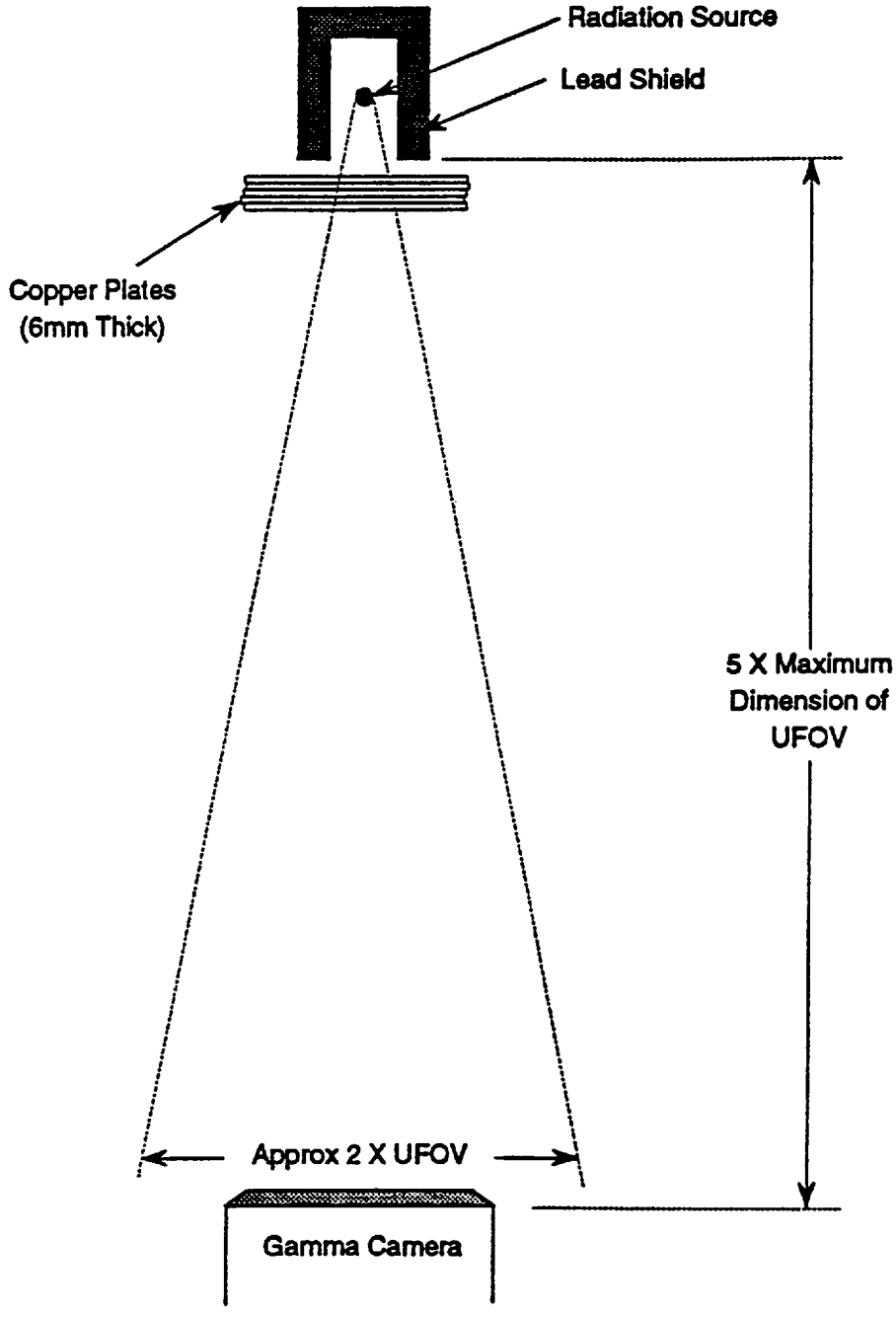


Figure 2-1
COLLIMATED SOURCE GEOMETRY

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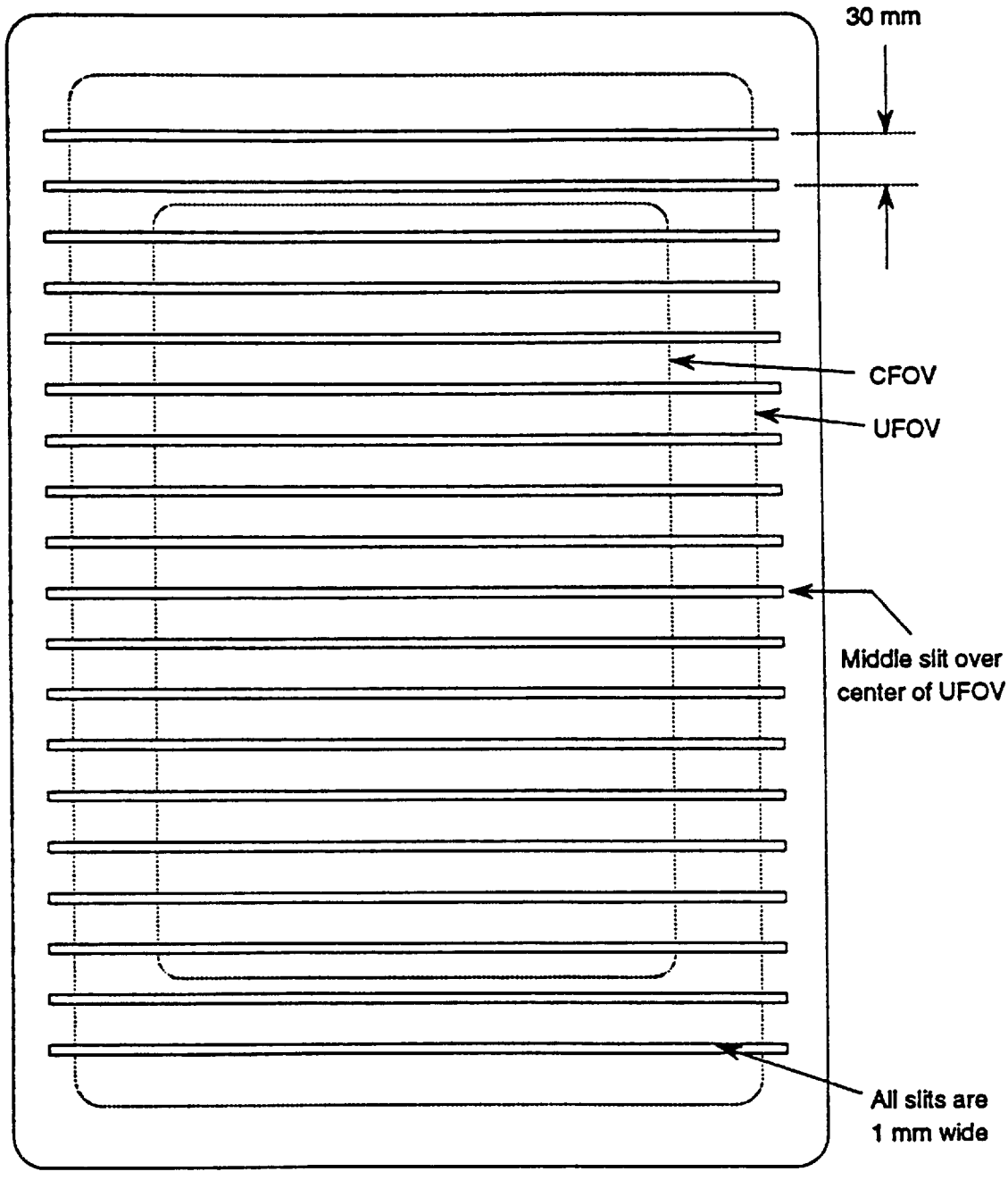
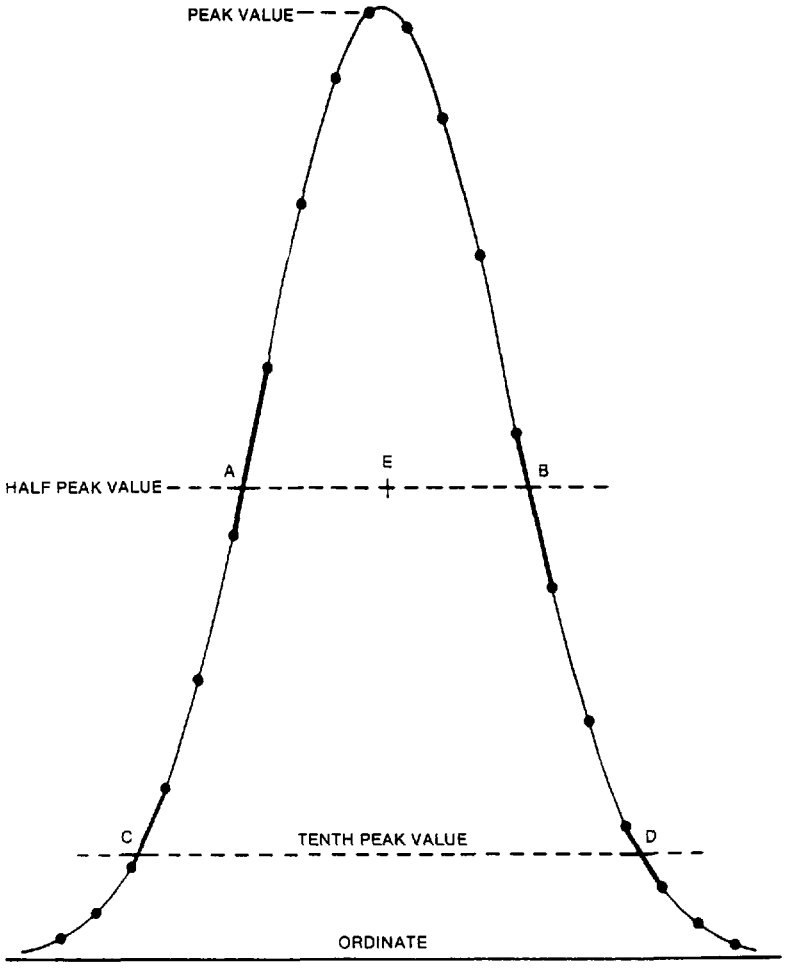


Figure 2-2
LEAD MASK FOR MEASUREMENT OF SPATIAL RESOLUTION AND LINEARITY

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Points A, B, (C, D) are found by linear interpolation from points surrounding half (tenth) peak value.

B – A = FWHM in channels

D – C = FWTM in channels

$\frac{A+B}{2}$ = E peak center, not the peak value point.

Figure 2-3
DETERMINATION OF FWHM AND FWTM

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2.1.5 Reporting

The calculated average FWHM and FWTM for a Tc-99m radionuclide shall be reported as a performance standard for both the UFOV and the CFOV, and given in millimeters with an accuracy of at least 0.1 mm.

Any other radionuclide employed shall be separately reported.

Measurements performed at any higher count rate than 20,000 cps shall also be separately reported.

2.2 INTRINSIC SPATIAL LINEARITY

Intrinsic spatial differential and absolute linearity shall be measured as performance standards. Differential linearity shall be expressed in millimeters as a standard deviation of the peak locations from a best fit line. Absolute linearity shall be expressed as the maximum displacement of a peak from the best fit of a two dimensional grid.

2.2.1 Test Conditions

The radionuclide employed for this test shall be Tc-99m. A source holder which shields the source from walls, ceilings, and personnel without restricting the photon flux from the source to the camera (as shown in Figure 2-1) shall be employed. The energy window shall be 20%. The count rate shall not exceed 20,000 cps through the energy window.

2.2.2 Test Equipment

The test pattern shall consist of a lead mask in closest possible proximity to the crystal covering the entire UFOV with 1 millimeter wide parallel slits. Adjacent slit centers shall be 30 mm one from the other (refer to Figure 2-2 which shows the geometry for a rectangular field of view camera). The thickness of the mask shall be 3 millimeters for Tc-99m.

2.2.3 Measurement Procedure

The lead mask with the parallel slits shall be positioned on the detector with the center slit centered on the detector. The center slit shall be perpendicular to the axis of measurement and aligned to within ±1 millimeter at the edge of the UFOV.

The radionuclide shall be a point source centered at least five times the largest linear dimension of the UFOV above the lead mask with the parallel slits.

The digital resolution perpendicular to the slits shall be less than or equal to 0.1 FWHM.

The data shall be integrated parallel to the direction of the slits to form line spread functions. The digital resolution parallel to the direction of the slits shall be less than or equal to 30 mm. At least 1,000 counts shall be collected in the peak channel of each line spread function measurement after integration parallel to the direction of the slits.

Two sets of data shall be acquired—one with the slits in the X direction and one in the Y direction.

2.2.4 Calculations and Analysis

If the data is acquired in a two dimensional matrix, the data shall be summed parallel to the direction of the slits to form line spread functions of width 30 mm or less.

The location of each of the peaks in each of the line spread functions shall be determined as the average of the interpolated half maximum locations on both sides of each peak. The half maximum locations shall be determined by linear interpolations from the nearest two neighboring points of the half peak value as described in Section 2.1.4 (see Figure 2-3). The locations of the peaks shall be calculated for each subsequent line spread function. This will generate a two dimensional array of peak locations. One dimension will be along the slits and one will be perpendicular to the slits. Note that there will be two two-dimensional arrays, one from data acquired with slits in the X direction and the other with slits in the Y direction.

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The value of intrinsic spatial differential linearity (in pixels) shall be calculated as the standard deviation of the locations of the peaks in each slit. The standard deviations for the slits in the X and Y directions shall be averaged together. Separate values shall be calculated for the UFOV and for the CFOV.

Intrinsic spatial absolute linearity shall be determined by fitting a two dimensional orthogonal grid of equally spaced points to the data using a least squares minimization technique. Different grids shall be fitted to the UFOV and to the CFOV data. There shall also be separate grids fitted for data acquired with the slits in the X and in the Y directions. The maximum displacement for each set shall be the largest difference between the data and the grid fit (in pixels) in the X or the Y direction.

The millimeters per channel calibration factor shall be calculated as described in Sections 2.1.4. This factor shall be used to convert the differential linearity and absolute linearity to millimeters.

2.2.5 Reporting

The intrinsic spatial differential linearity shall be reported as a performance standard for both the UFOV and for the CFOV. The values shall be given in millimeters with an accuracy of at least 0.1 mm.

The intrinsic spatial absolute linearity shall be reported as a performance standard for both the UFOV and for the CFOV. The values shall be given in millimeters with an accuracy of at least 0.1 mm.

2.3 INTRINSIC ENERGY RESOLUTION

Intrinsic energy resolution shall be measured as a performance standard and expressed as the ratio of the photopeak FWHM to the photopeak center energy, given as a percentage.

2.3.1 Test Conditions

The radionuclide employed for this test shall be Tc-99m. A source holder which shields the source from walls, ceilings and personnel without restricting the gamma flux from the source to the camera (as shown in Figure 2-1) shall be employed. The detector shall be masked with a 3 mm thick lead aperture to establish UFOV. The integral count rate shall not exceed 20,000 cps.

2.3.2 Test Equipment

The test equipment shall include means to digitize the energy spectrum with a channel depth of at least 10,000 counts, and a digital resolution of less than or equal to 0.05 FWHM of Tc-99m photopeak.

2.3.3 Measurement Procedure

The radionuclide shall be a Tc-99m point source centered at least five times the largest linear dimension of the UFOV above the detector. A second radionuclide, Co-57, shall be employed as a reference in order to determine the keV per channel calibration factor. The spectra for Tc-99m and Co-57 shall be separately stored. At least 10,000 counts shall be stored in the peak channel of each spectra measurement.

2.3.4 Calculations and Analysis

For each of the stored spectra, the photopeak location shall be determined as the average of the linearly interpolated half height channel values, calculated for each side of the photopeak (see Figure 2-3). The difference between the two photopeak locations in channel numbers should correspond to 18.4 keV, which is the difference between 140.5 keV of the Tc-99m photopeak center energy and the 122.1 keV of the Co-57 photopeak center energy. The intrinsic energy resolution shall be calculated from the Tc-99m stored spectrum. The FWHM in channel numbers shall be determined from the linearly interpolated half height channel values and calculated for each side of the Tc-99m photopeak. This value shall be multiplied by the keV's per channel calibration factor, divided by 140.5 keV corresponding to the Tc-99m photopeak center energy, and multiplied by 100 in order to obtain the value as a percentage.

2.3.5 Reporting

The calculated intrinsic energy resolution over the UFOV for a Tc-99m radionuclide shall be reported as a performance standard and expressed as a percentage.

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Any other radionuclides employed shall be separately reported.

Measurements performed at any higher count rate than 20,000 cps shall also be separately reported.

2.4 INTRINSIC FLOOD FIELD UNIFORMITY

As a performance standard, the intrinsic uniformity of the system shall be measured for the CFOV and UFOV.

The intrinsic uniformity is the response of the system without a collimator to a uniform flux of radiation from a point source. Two different uniformity parameters shall be determined: integral uniformity and differential uniformity. Integral uniformity is a measure of the maximum pixel count deviation in the CFOV or UFOV. Differential uniformity is a measure of the maximum deviation over a limited range designed to approximate the size of a photomultiplier tube.

2.4.1 Test Conditions

The radionuclide used to measure intrinsic uniformity is to be Tc-99m. Any other radionuclide used shall be reported separately. The count rate shall not exceed 20,000 counts per second through a symmetric 20% photopeak window. The status of uniformity corrections used shall be stated with the results.

2.4.2 Test Equipment

The test equipment required for this measurement consists of a source holder, a lead mask for the detector, and a computer or multi-channel analyzer. The source holder shall consist of a lead shield to prevent back and side scatter but be open at the front so that it does not restrict the gamma flux from the source to the detector. The source holder is shown in Figure 2-1. The lead mask for the detector is a lead aperture of at least the dimensions of UFOV.

2.4.3 Measurement Procedure

The detector shall be masked using a lead mask described above. The source in the source holder shall be placed on the central axis of the detector. The distance from the detector to the source shall be at least five times the largest dimension of the UFOV. The flood field image shall be stored in a matrix size which produces pixel sizes with a linear dimension of 6.4 mm ± 30%. The pixels shall be square.

A minimum of 10,000 counts shall be collected in the center pixel of the image.

2.4.4 Calculations and Analysis

Prior to performing the uniformity calculations, the pixels for inclusion shall be determined as described below.

First, any pixels at the edge of UFOV containing less than 75% of the mean counts per pixel in CFOV, shall be set to zero.

Second, those pixels which have at least one of their four directly abutted neighbors containing zero counts, will be also set to zero. The remaining non-zero pixels are the pixels to be included in the analysis for the UFOV.

This step shall be performed only once. Any pixel which has at least 50% of its area inside the CFOV shall be included within the CFOV analysis.

2.4.4.1 DATA PREPARATION

The flood field image, after removing the edge pixels, shall be smoothed once by convolution with a 9 point filter function of the following weightings:

1	2	1
2	4	2
1	2	1

The weighting factor for a pixel outside the analysed area in the 9 point filter function shall be zero. The smoothed value shall be normalized by dividing by the sum of non zero weighting factors.

2.4.4.2 INTEGRAL UNIFORMITY

For pixels within each area (CFOV and UFOV), the maximum and the minimum values are to be found from the smoothed data. The difference

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between the maximum and the minimum is divided by the sum of these two values and multiplied by 100% .

Integral Uniformity = ± 100% ((Max - Min) / (Max + Min))

Equation 2.4.4-1

2.4.4.3 DIFFERENTIAL UNIFORMITY

For pixels within each area (CFOV and UFOV) the largest difference between any two pixels within a set of 5 contiguous pixels in a row or column shall be calculated. The calculation shall be done for the X and for the Y directions independently and the maximum change expressed as a percentage using the following:

Differential Uniformity = ± 100% ((Max - Min) / (Max + Min))

Equation 2.4.4-2

The filtered data are treated as a number of rows (X slices) and columns (Y slices). Each slice is processed by starting at the beginning pixel for the respective field of view. A set of five contiguous pixels is examined to find the maximum and minimum pixels. The differential uniformity is calculated using these values. The next set of five pixels is analyzed by stepping forward one pixel and again determining the percent uniformity. This is repeated until the outermost pixel is reached. The maximum differential uniformity is found in the slice. This process is then repeated for all of the slices.

2.4.5 Reporting

The result is reported as a class standard and expressed as the percentage integral and differential uniformity for both of the CFOV and the UFOV.

2.5 MULTIPLE WINDOW SPATIAL REGISTRATION

Multiple window spatial registration shall be measured and reported as a performance standard. Multiple window spatial registration is a measure of the camera's ability to accurately position photons of different energies when imaged through different photopeak energy windows. Measurements shall be made at nine specified points on the entrance plane of the scintillation camera.

2.5.1 Test Conditions

The radionuclide used to measure multiple window spatial registration shall be Ga-67. The count rate shall not exceed 10,000 counts per second through each symmetric 20% photopeak energy window.

2.5.2 Test Equipment

A lead-lined source holder shall collimate the Ga-67 source through a cylindrical tunnel in the lead. This circular tunnel shall be 5 mm in diameter and 25 mm in length. See Figure 2-4 for a sketch of the Ga-67 source inside such a source holder.

2.5.3 Measurement Procedure

Images shall be acquired using the above described collimated Ga-67 source (see Figure 2-4) located at nine specific points on the entrance surface of the uncollimated camera. These nine points shall be the central point, four points on the X axis and four points on the Y axis. The off central points shall be located 0.4 times and 0.8 times the distance from the central point to the edge of the UFOV of the camera along the respective axes. Separate images of the collimated Ga-67 source shall be acquired through separate energy windows of the Ga-67 photopeaks at each of these image locations. These images shall be acquired with a pixel size of not more than 2.5 mm. For cameras with two energy windows, two images shall be acquired at each point; one using the 93 keV photopeak and the second using the 300 keV photopeak. For cameras with three or more energy windows, the 184 keV photopeak shall also be imaged. At least 1,000 counts shall be acquired in the peak pixel of each photopeak image.

2.5.4 Calculations and Analysis

The displacement of the count centroids from each other in the X and Y directions shall be determined for each measurement point's photopeak images. A square region of interest (ROI) centered on the maximum count pixel associated with each photopeak image shall be used to analyze the individual photopeak images.

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The pixel dimensions of the square ROI shall be approximately four times the FWHM of the image count profile to be analyzed. Each image shall be integrated in the Y direction to determine the X count profile and integrated in the X direction to determine the Y count profile. The centroid of counts in the X and Y directions shall be determined for each image from that direction's count profile by the method described below. The maximum difference in position of the centroid of counts acquired from each photopeak shall be determined. The largest pixel displacement shall then be converted to millimeters using an accurate millimeter per pixel calibration from Section 2.1.4.

2.5.4.1 METHOD FOR CENTROID OF COUNTS DETERMINATION

The center of counts in the X and Y directions for each of the photopeak count profiles shall be determined as follows. Find the maximum count pixel in the integrated X or Y profile and calculate the centroid of counts using the following formula:

$$L_j = \sum_{i=1}^{n} (X_i \times Ci) / \sum_{i=1}^{n} Ci$$

Equation 2.5.4.1

Where:

L_j = calculated centroid location for energy window j where j can equal 1, 2 or 3

X_i = X or Y count profile pixel at the ith location

Ci = counts at the X_i or Y_i location

$\sum_{i=1}^{n}$ = is the sum over an odd number of count profile pixels centered on the maximum count profile pixel. The exact odd number of pixels will depend on the FWHM of the count profile and the pixel size. The minimum number of pixels in this sum shall include both the left and right half maximum counts.

The displacement D_{ij} between energy windows i and j is then:

$$D_{ij} = | L_i - L_j |$$

Where:
i = 1, 2 or 3
j = 1, 2 or 3

Equation 2.5.4-2

The maximum displacement is simply the largest D_{ij}.

2.5.5 Reporting

The multiple window spatial registration shall be reported as the maximum displacement in either the X or Y direction of the photopeak count centroids for the nine points measured. This performance standard shall be reported in millimeters to the nearest tenth of a millimeter.

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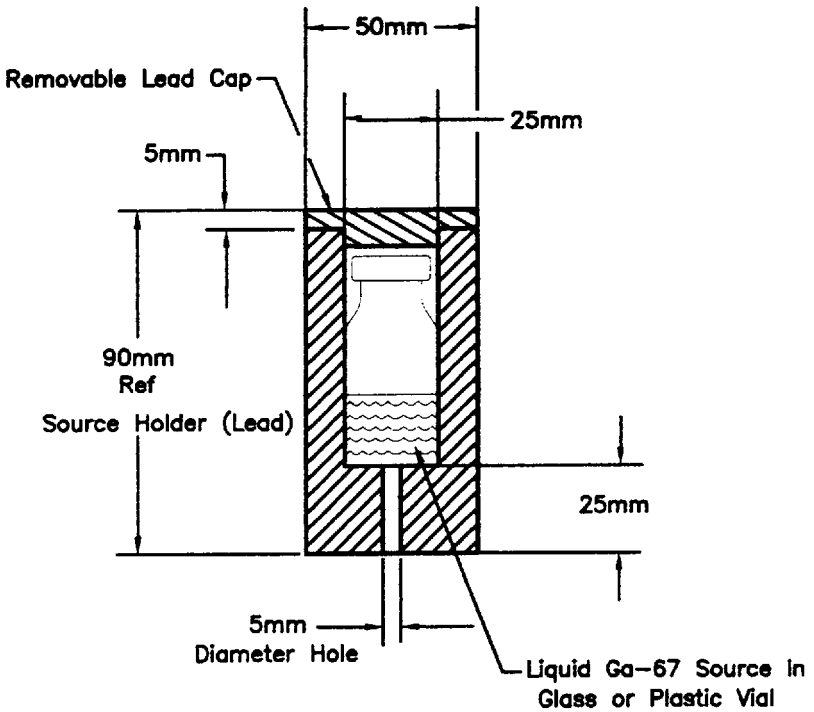


Figure 2-4
CYLINDRICAL Ga-67 SOURCE HOLDER SHOWING LIQUID SOURCE INSIDE

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Section 3
SINGLE CRYSTAL SCINTILLATION CAMERA TEST METHODS: CLASS STANDARDS

3.1 INTRINSIC COUNT RATE PERFORMANCE IN AIR

Decaying source method shall be used to determine count rate performance. Two parameters shall be measured and reported: observed count rate for a 20% count loss and a maximum count rate. Both parameters shall be measured without induced scatter. The curve of observed versus input count rates shall be provided.

3.1.1 Test Conditions

The radionuclide employed for the test shall be Tc-99m. Any other radionuclide(s) employed shall be separately reported.

The energy window shall be 20% centered on the photopeak. Peaking shall be performed at a low count rate and shall not be manually readjusted during the test. The camera shall be tested in normal mode per Section 1.3.3.

3.1.2 Test Equipment

A camera under test shall have the camera crystal masked to the UFOV.

The source shall be placed within a lead container as in Figure 3-1. The open side (facing the camera crystal) shall be covered by 6 mm of copper plates. The source intensity shall be such that it produces an input count rate which is larger than the count rate required to cause foldover in the observed count rate.

3.1.3 Measurement Procedure

Determine the background count, N_{bkg}. The suggested time for this determination is 10 minutes. The lead holder with the source shall be placed in a suitable position in front of the detector. The source holder shall be positioned so that the collimated cone of radiation is centered within the UFOV and that the irradiated area of the crystal extends fully across the smaller dimension of the UFOV. Care must be taken to minimize scatter.

The start (t_i) and elapse time (Δt_i) of the measurement shall be recorded for each data point, where (i) is the number of the data point.

The time shall be measured relative to the start of acquisition time of the measurement of the first data point. For each data point (Ci), at least 100,000 counts shall be collected. Data should be acquired for 10 sec. or 100,000 counts, which ever time is longer.

The measurement should be performed so that the points are taken as soon as the observed count rate drops by 10,000 cps below the previous measured point. The last (n-th) point taken should be measured when the observed count rate drops below 4,000 cps.

3.1.4 Calculations and Analysis

The observed count rate (OCR_i) shall be determined for each data point according to the following formula:

$$OCR_i = \frac{(Ci - N_{bkg} * \Delta t_i) * \ln(2)}{21672 * (1 - \exp((-\Delta t_i)/21672 * \ln(2)))}$$

Equation 3.1.4-1

21672 represents the number of seconds in one half life of Tc-99m where all the measurement times are in seconds, or fractions thereof.

The input count rate (ICR_i) for each data point shall be calculated according to the following formula:

$$ICR_i = OCR_n * \exp((t_n - t_i)/21672 * \ln(2))$$

Equation 3.1.4-2

The observed count rate at 20% loss shall be determined by linear interpolation between the two closest points to the equation:

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$$OCR_i = 0.8 \times ICR_i$$

Equation 3.1.4-3

Explanation:

The purpose of Equation 3.1.4-1 is to scale the measurements (calculate the observed count rate corrected for background) to the time at the beginning of the measurement of each data point t_i.

When the measurement is performed at high count rates, the duration of the measurement has little or no effect. That is to say that Tc-99m will decay very little during a few seconds of the measurement at count rates of, e.g. 150,000 cps. However, when the count rate approaches 4,000 cps and if 100,000 counts are collected, the measurement will take more than 25 seconds, during which time Tc-99m will decay by roughly 0.1% .

Equation 3.1.4-1 takes care of this problem by subtracting the appropriate amount of background counts from the number of counts collected and then scaling this number according to the exponential decay law. The resulting observed count rate points are now scaled to the time at the beginning of the measurement of each data point; i.e. OCR_i is the number that would be obtained if we could instantaneously measure only the counts coming from the source (no background).

Equation 3.1.4-2 simply extrapolates the measurement taken at the last point (at a very low count rate) to the points at high count rates. This is reasonable because the dead time at the count rates below 4,000 cps is only a fraction of a percent. This relative error is propagated through extrapolation, but it is not amplified (i.e. it will always retain the same percentage).

The largest effect, by far, is caused by the background measurement. Effort should be maintained to minimize variations in background throughout the test.

3.1.5 Reporting

The maximum observed count rate, the observed count rate at 20% loss, and the curve of observed count rate vs. the input count rate shall be reported as Class Standards.

3.1.6 Technical Note

This test is very time consuming, approximately 2 days. An alternative method is to use carefully calibrated copper sheets as discussed in the following articles:

1. "*A New Approach to NEMA Scintillation Camera Count Rate Curve Determination*," by E.M. Geldenhuys et al, JNM Vol. 29, No. 4, April 1988 p. 538.

2. "*Spectral Changes Affect Intrinsic Count Rate Tests*," by Stephen I. Breen / Trevor D. Cradduck, JNM Vol. 31, No. 12, December 1990, p. 2074.

Traceability of this method to above standard must be demonstrated.

3.2 SYSTEM COUNT RATE PERFORMANCE WITH SCATTER

Decaying source method shall be used to determine count rate performance. Two parameters shall be measured and reported: observed count rate for a 20% count loss and a maximum count rate. Both parameters shall be measured with induced scatter. The curve of observed versus input count rates shall be provided.

3.2.1 Test Conditions

The radionuclide employed for the test shall be Tc-99m. Any other radionuclide(s) employed shall be separately reported.

The energy window shall be 20% centered on the photopeak. Peaking shall be performed at a low count rate and shall not be manually readjusted during the test. The camera shall be tested in normal mode per Section 1.3.3.

3.2.2 Test Equipment

A camera under test shall have a low energy collimator mounted. The source shall be in a liquid solution filling a disk container as shown on Figure 3-2. The source intensity shall be such that it produces an input count rate which is larger than the count rate required to cause foldover in the observed count rate.

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The source shall be placed within a plastic cylindrical phantom with dimensions shown in Figure 3-2.

3.2.3 Measurement Procedure

The detector shall be positioned to view the 50 mm thick plastic base of the phantom. The distance between the phantom and the face of the collimator shall not be greater than 20 mm. The phantom shall be centered within the UFOV.

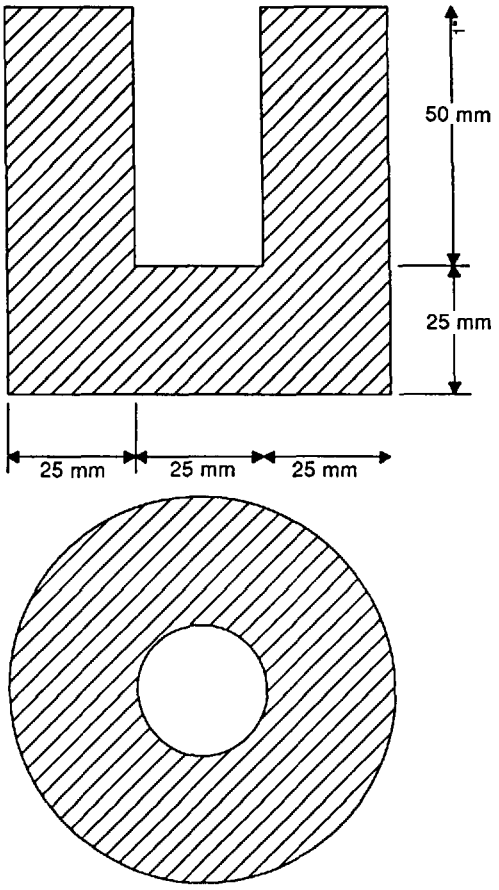


Figure 3-1
SOURCE HOLDER SHIELD FOR COUNT RATE TESTS

Prior to the beginning of the measurement, the background count rate, N_{bkg} shall be determined. The start (t_i) and elapsed time (Δt_i) of the measurement shall be recorded for each data point, where (i) is the number of the data point.

The time shall be measured relative to the start of acquisition time of the measurement of the first data point. For each data point (Ci), at least 100,000 counts shall be collected. Data should be acquired for 10 sec. or 100,000 counts, whichever time is longer.

The measurement should be performed so that the points are taken as soon as the observed count rate drops by 10,000 cps below the previous measured point. The last (n-th) point taken should be measured when an observed count rate drops below 4,000 cps.

3.2.4 Calculations and Analysis

The observed count rate (OCR_i) shall be determined for each data point according to the following formula:

$$OCR_i = \frac{(Ci - N_{bkg} * \Delta t_i *) \ln (2)}{21672 * (1 - \exp(-\Delta t_i)/21672 * \ln (2)))}$$

Equation 3.2.4-1

21672 represents the number of seconds in one half life of Tc-99m where all the measurement times are in seconds, or fractions thereof.

The input count rate (ICR_i) for each data point shall be calculated according to the following formula:

$$ICR_i = OCR_n * \exp((t_n - t_i)/21672 * \ln (2))$$

Equation 3.2.4-2

The observed count rate at 20% loss shall be determined by linear interpolation between the two closest points to the equation:

$$OCR_i = 0.8 \times ICR_i$$

Equation 3.2.4-3

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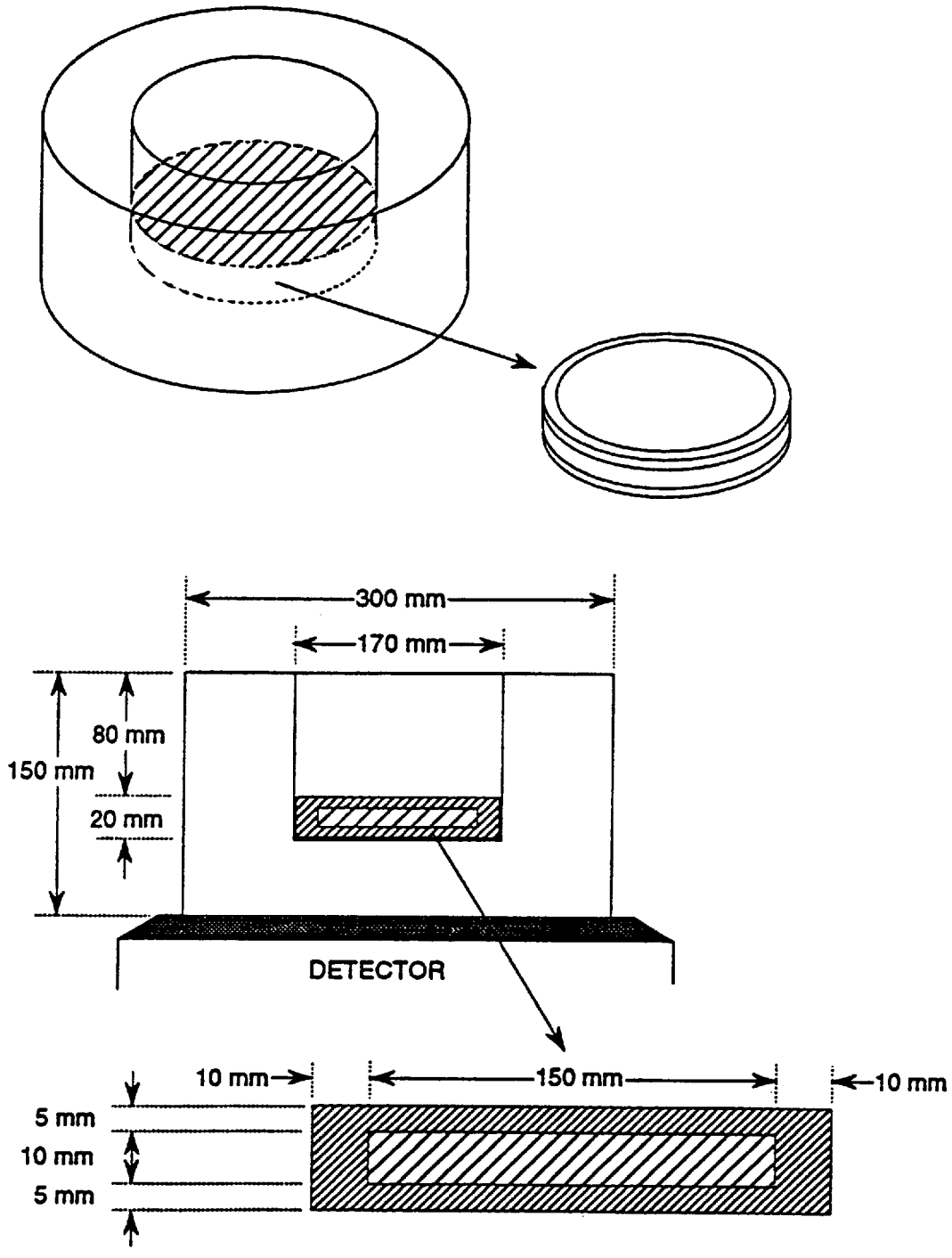


Figure 3-2
PHANTOM FOR MEASURING COUNT RATE PERFORMANCE IN SCATTER

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3.2.5 Reporting

The maximum observed count rate, the observed count rate at 20% loss, and the curve of observed count rate with scatter versus the input count rate shall be reported as class standards.

3.3 INTRINSIC SPATIAL RESOLUTION AT 75,000 COUNTS PER SECOND

Intrinsic spatial resolution shall be measured at 75,000 counts per second, and average FWHM and average FWTM reported as class standard, following the procedures and reporting requirements of Section 2.1.

3.4 INTRINSIC FLOOD FIELD UNIFORMITY AT 75,000 COUNTS PER SECOND

Intrinsic flood field uniformity shall be measured at 75,000 counts per second and the integral and differential uniformity for both CFOV and UFOV reported as class standards following the procedures and reporting of Section 2.4.

3.5 SYSTEM SPATIAL RESOLUTION WITH AND WITHOUT SCATTER

As a class standard, the system spatial resolution with and without scatter shall be measured and expressed as FWHM and FWTM of the line spread function.

3.5.1 Test Conditions

The radionuclides employed for these measurements shall be those for which the collimators were designed. The count rate shall not exceed 20,000 cps through a symmetric 20% energy window or windows.

3.5.2 Test Equipment

The test equipment required for these measurements shall consist of two capillary tubes with an inside diameter of less than or equal to 1.0 mm and a length greater than 30 mm. Also, acrylic scattering blocks, the size of the UFOV of the system to be measured and 100 and 50 mm thick, are required for the "with scatter" measurements. The required acrylic scattering thickness may be assembled from thinner pieces but still must cover the entire UFOV.

3.5.3 Measurement Procedure

The capillary tubes shall be filled with the desired radionuclide. One of these tubes shall be positioned 100 mm from the face of the system collimator and along the diameter corresponding to the axis of measurement, X or Y.

The digital resolution perpendicular to the tube shall be ≤0.1 FWHM and the digital resolution parallel to the tube shall be no greater than 30 millimeters. At least 10,000 counts shall be collected in the peak point of each line spread function.

Measure the FWHM and FWTM in pixels of all the line spread functions that fall within the CFOV, first in the X direction and then in the Y direction, using the method of 2.1.4.

A second measurement for each axis shall be performed with the second capillary tube also positioned 100 mm from the face of the collimator and 50 mm away from, and parallel to, the first tube. This measurement shall be used for calibration of the millimeters per pixel only. The single capillary tube measurement shall then be repeated using the acrylic scattering blocks. The capillary tube remains 100 mm from the face of the collimator and sandwiched between the 100 mm thick forward scattering block and the 50 mm back scattering block.

3.5.4 Calculations and Analysis

Convert the FWHM and FWTM measurements from pixels to millimeters, using the measured millimeter per pixel calibration factor. Average the appropriate "without scatter" measurements in both the X and Y directions. Average the appropriate "with scatter" X and Y direction measurements together.

3.5.5 Reporting

System spatial resolution, with and without scatter shall be reported as FWHM and FWTM within the CFOV. This shall be reported as a class standard. Collimator and the radionuclide employed shall be also reported.

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3.6 SYSTEM PLANAR SENSITIVITY

The planar sensitivity is the sensitivity in one acquisition plane to a specific planar source placed parallel to that plane. Planar sensitivity measurements are dependent on collimator type, window width, gamma energy, source configuration and other factors.

The planar sensitivity of the system shall be measured for each collimator type and reported in counts/min/MBq or counts/min/μCi.

3.6.1 Test Conditions

The radionuclides employed for these measurements shall be those for which the collimators are designed. The count rate shall not exceed 20,000 counts per second through a symmetric 20% energy window or windows.

3.6.2 Test Equipment

The test equipment required for this measurement consists of a 1 to 5 cc plastic syringe, a calibrated dose calibrator, and a 100 mm diameter flat plastic dish (petri dish).

3.6.3 Measurement Procedure

The source activity inside the plastic syringe shall be accurately measured using a dose calibrator. This source shall then be dispersed from the syringe into an approximately 3 mm deep water solution in a 100 mm diameter flat plastic dish.

The empty syringe shall be re-measured in the dose calibrator and the reading subtracted from the original reading to obtain the amount of activity in the dish at the time of preparation.

Calibration methods shall be those set forth in the NRC Regulatory Guide 10.8, or alternatively NIST traceable calibration sources shall be used as references with appropriate half life corrections.

The prepared dish source shall be placed near the center of the field of view and in a plane 100 mm from the face of the collimator. No scatter material shall be present.

Accurately determine the counts per minute recorded by the imaging system. Field uniformity correction devices, or any other mechanisms that alter the number of counts, must be disabled.

3.6.4 Calculations and Analysis

Divide the determined number of counts per minute by the activity in MBq, or μCi at the time of the measurement to get the planar sensitivity of the system.

1 micro Curie = .037 million Becquerels

3.6.5 Reporting

Report the planar sensitivity for the system in counts/min/MBq or counts/min/μCi. It shall be reported as a class standard. The radionuclide and collimator shall be stated.

3.7 DETECTOR SHIELDING

Shield leakage is the penetration of the shielding by sources placed 10 cm from the detector housing and reported as a leakage in counts/minute/MBq or counts/min/μCi.

3.7.1 Test Conditions

Shield leakage she'll be reported for Tc-99m and for a source specified with the maximum design energy of the camera. The counting rate, when the source is placed 10 cm in front of the collimator of specified energy, shall be less than 10,000 cps through a symmetric 20% energy window.

The counting rate through the shielding shall be measured while the specified collimator is mounted to the camera.

3.7.2 Test Equipment

The test equipment for this measurement consists of a source holder shown in Figure 2-4 and a collimator of the specified energy. The vial containing the source shall be completely filled with liquid.

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3.7.3 Measurement Procedure

The source shall be placed in the source holder. The source shall be imaged through the collimator of specified energy and the counting rate recorded after counting at least 10,000 counts and recording the length of the time.

The source shall be moved around the detector at a distance of 10 cm from the detector. Move around the sides and back of the detector to find the location of maximum counts. The source shall be counted at this location until the source, plus background counts, are greater than three standard deviations above the background counts, i.e., leakage counts and background counts greater than three times square root of background counts.

Note that care must be taken to avoid Compton scatter from the source into the face of the collimator while measuring shield leakage.

3.7.4 Calculations and Analysis

The percent shielding leakage shall be calculated and reported as a number.

$$\text{Shielding Leakage} = \frac{\text{Maximum Shield Count Rate}}{\text{Collimator Count Rate}} * 100$$

Equation 3.7.4-1

3.7.5 Reporting

The shield leakage shall be reported as a class standard for Tc-99m and the highest energy radionuclide for which the detector is designed. The collimator used for measurement shall be specified.

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Section 4
SINGLE CRYSTAL SCINTILLATION CAMERA TEST METHODS FOR SINGLE PHOTON EMISSION COMPUTED TOMOGRAPHY: PERFORMANCE STANDARDS

4.1 RECONSTRUCTED SPATIAL RESOLUTION WITHOUT SCATTER

The reconstructed spatial resolution of the system shall be measured at three specified points in air. FWHM values of resolution in the X, Y and Z direction shall be determined for these three points.

4.1.1 Test Conditions

Three Tc-99m or Co-57 point sources shall be used for these measurements. The count rate shall not exceed 20,000 cps through a symmetric 20% energy window(s).

No table shall come between the sources and the detector in any view.

4.1.2 Test Equipment

Three thin-walled glass capillary tubes or equivalent shall be used to form and position the point sources as defined in Figure 4-1. These three point sources shall be made as spherically symmetric as possible with a maximum dimension no larger than 2 mm.

4.1.3 Measurement Procedure

Position the plane of the three point sources parallel to the plane of the table, with the central point source positioned on the axis of rotation and centered in the field of view within ±5 mm. The radius of rotation for the circular orbit shall be 150 ± 5 mm. The data shall be collected and reconstructed in a matrix with an effective pixel size of less than or equal to 2.5 mm. At least 20,000 total counts must be acquired in each of at least 120 different projection angle images over 360° utilizing step and shoot mode.

4.1.4 Calculations and Analysis

One 130 ± 5mm thick transverse slice, centered on the central point source, shall be reconstructed from raw projection data using the filtered back projection technique with a ramp filter. If, in addition, other reconstruction techniques are used, they shall be specified. This transverse slice will contain an image of the three point sources.

Likewise, one 180 ± 5 mm thick sagittal slice, centered on the central point source, shall be reconstructed. This slice will also contain an image of the three point sources.

Likewise, one 30 ± 5 mm thick coronal slice shall be reconstructed, with the slice thickness centered on the plane of the three point sources.

4.1.4.1 ANALYSIS OF POINT IMAGES

Each of these nine point source images contained in the three slices shall be analyzed individually within a square region of interest (ROI) centered on the maximum count pixel associated with this point. The dimension of the square ROI must be at least four times the anticipated FWHM to be analyzed. Each point image shall be integrated in the Y direction to determine the X direction point spread function and integrated in the X direction to determine the Y direction point spread function.

4.1.4.2 FULL WIDTH HALF MAXIMUM (FWHM) CALCULATIONS

The FWHM in X and Y for each of the above nine point images shall be calculated according to the method described in Section 2.1.4. Record these measured values in worksheet 4-1 for the central point and on worksheet 4-2 for the peripheral points.

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Worksheet 4-1	Central Point Measurements		
Transverse Slice	X =	Y =	
Sagittal Slice		Y =	Z =
Coronal Slice	X =		Z =
Average Values	$\bar{X}$ =	$\bar{Y}$ =	$\bar{Z}$ =
Transaxial Avg.	$\frac{\bar{X} + \bar{Y}}{2}$ =		

Worksheet 4-2	Periphreal Points Measurements		
	Point 1		
Transverse Slice	X =	Y =	
Sagitta Slice		Y =	Z =
Coronal Slice	X =		Z =
	Point 2		
Transverse Slice	X =	Y =	
Sagittal Slice		Y =	Z =
Coronal Slice	X =		Z =
Average Values	$\bar{X}$ =	$\bar{Y}$ =	$\bar{Z}$ =

4.1.5 Reporting

Five FWHM average values shall be reported as performance standards. Two FWHM values are reported for the central point and three FWHM values are reported for the peripheral points:

Central Transaxial $\frac{(\bar{X} + \bar{Y})}{2}$

Central Axial $(\bar{Z})$

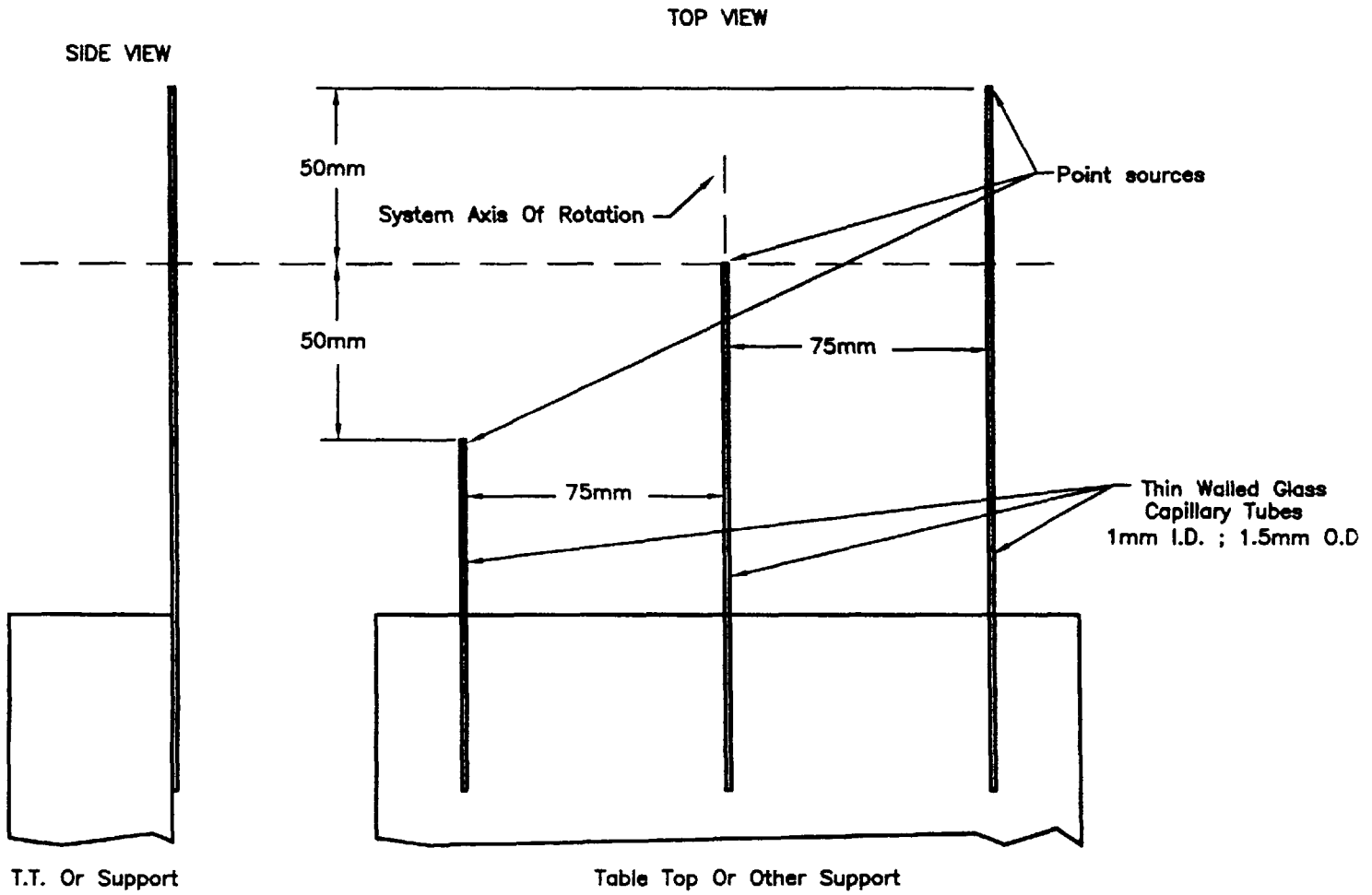
Peripheral Radial $(\bar{X})$

Peripheral Tangential $(\bar{Y})$

Peripheral Axial $(\bar{Z})$

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Note: Point sources can be made by placing the tip of a capillary tube in the radionuclide solution. By holding the opposite end closed; the tube may be removed with the point source enclosed and sealed with a capillary tube sealer.

Figure 4-1
FIXTURING AND POSITION OF THE THREE PLANAR POINT SOURCES

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Section 5
SINGLE CRYSTAL SCINTILLATION CAMERA TEST METHODS FOR SINGLE PHOTON EMISSION COMPUTED TOMOGRAPHY: CLASS STANDARDS

5.1 RECONSTRUCTED SPATIAL RESOLUTION WITH SCATTER

As a class standard, the reconstructed transaxial spatial resolution shall be measured using three line sources in a cylinder of water.

5.1.1 Test Conditions

Tc-99m or Co-57 line sources shall be used with a symmetric photopeak energy window of 20%. The count rate shall not exceed 20,000 cps.

5.1.2 Test Equipment

The phantom shall consist of a water filled acrylic cylinder with an inside diameter of 20 mm and containing three axial line sources with a diameter of 1 mm. This phantom is described specifically in Figure 5-1.

5.1.3 Measurement Procedure

The specified phantom shall be aligned with the system's axis of rotation within ± 2 mm and centered in the field of view. The phantom shall be imaged using a 360° circular orbit SPECT acquisition of radius 150 ± 5 mm. The acquisition reconstructed matrix size shall have an effective pixel size of less than or equal to 2.5 mm. At least 100,000 total counts must be acquired in each of at least 120 different projection angle images or 360° utilizing step and shoot mode.

5.1.4 Calculations and Analysis

One transverse slice, 10 ± 3 mm in thickness, shall be reconstructed through the center of the phantom using the filtered back projection technique with a ramp filter. If, in addition, other reconstruction techniques are used, they shall be specified with the results.

Two additional transverse slices, each 10 ± 3 mm in thickness, shall also be reconstructed and centered about ± 40 mm from the center along the axis of rotation.

The three reconstructed points in each of the three reconstructed slices shall be analyzed individually with a square region of interest. Each region of interest shall be centered on the maximum count pixel. The size of this square region of interest must be at least four times the anticipated FWHM of the count profile to be analyzed.

For each point in the images, the FWHM in X and Y shall be determined according to the method described in Section 2.1.4.

Referring to Figure 5-2, the average FWHM radial value of the six radial measurements on the three slice images of the two peripheral sources shall be calculated. Likewise, the average tangential FWHM value of the six tangential measurements on the images of the two peripheral sources shall be calculated. Also, the average of the six measurements (three in the X direction and three in the Y direction) for the three images of the center source shall be calculated.

5.1.5 Reporting

As a class standard, three FWHM resolution values shall be reported: one FWHM value for the central source and two FWHM values for the peripheral sources (one for the radial direction and one for the tangential direction). All FWHM resolution values shall be reported in millimeters to the nearest one tenth of a millimeter.

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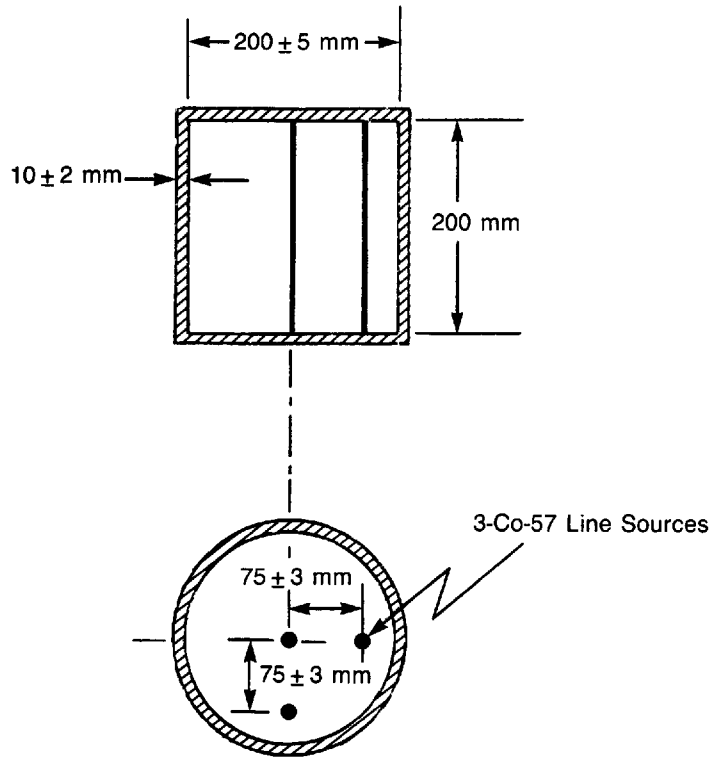


Figure 5-1
RECONSTRUCTED SYSTEM SPATIAL RESOLUTION

5.2 SYSTEM VOLUME SENSITIVITY

As a class standard, the system volume sensitivity shall be measured and the average volume sensitivity per axial centimeter determined from this measurement. The system volume sensitivity is the total system sensitivity to a uniform concentration of activity in a specific cylindrical phantom. System volume sensitivity measurements are dependent on detector configuration, collimator type, radionuclide type, energy window setting, source configuration and other factors.

5.2.1 Test Conditions

The radionuclides employed for these measurements shall be those for which the collimators were designed. The measurement count rate for each projection image shall be 10,000 ± 2000 cps through a symmetric 20% photopeak energy window or windows.

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5.2.2 Test Equipment

The test equipment required for this measurement consists of a plastic syringe, an accurate dose calibrator and a specified 20 mm diameter cylindrical phantom, described in Figure 5-3.

5.2.3 Measurement Procedure

Accurately determine the activity concentration in kBq/cm^3 within the specified cylindrical phantom at initial time T_i. This is done by dividing the measured activity placed in the phantom at T_i by the measured volume of water in the phantom.

This well-mixed and uniform cylindrical source shall be positioned in the center of the system's image space with its symmetry axis coincident within ± 5 mm of the axis of rotation of the SPECT system.

Perform a 360° circular orbit SPECT acquisition of radius 150 ± 5 mm. At least 120 but not more than 128 different projection angle images shall be acquired. Each projection image shall contain 100,000 ± 20,000 counts through a 20% symmetric photopeak window. For multihead systems, the images from all heads may be summed to achieve the required number of projection images. Field uniformity correction devices or any other mechanisms which alter the number of counts in these projection images must be disabled.

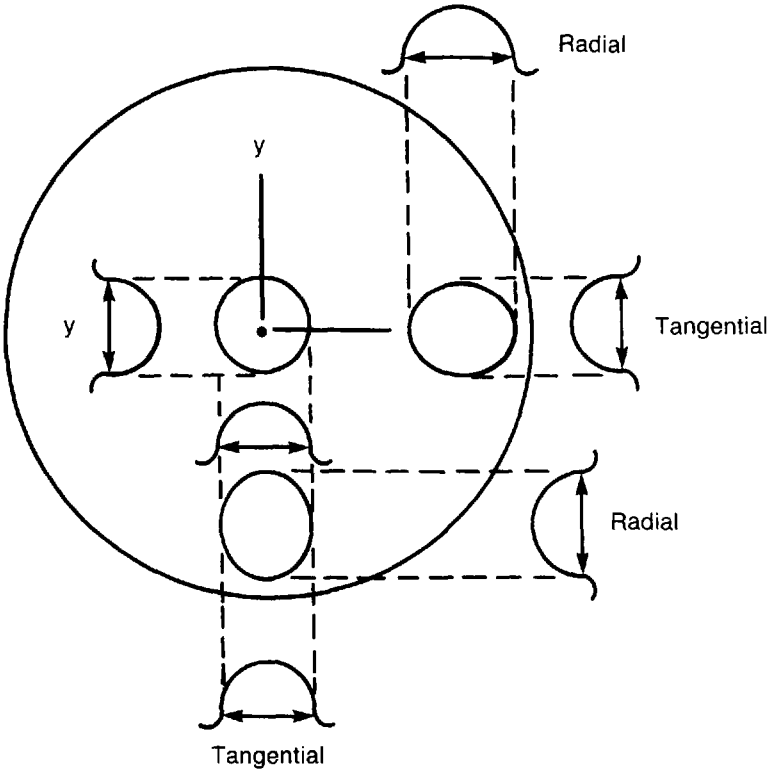


Figure 5-2
REPORTING SPATIAL RESOLUTION

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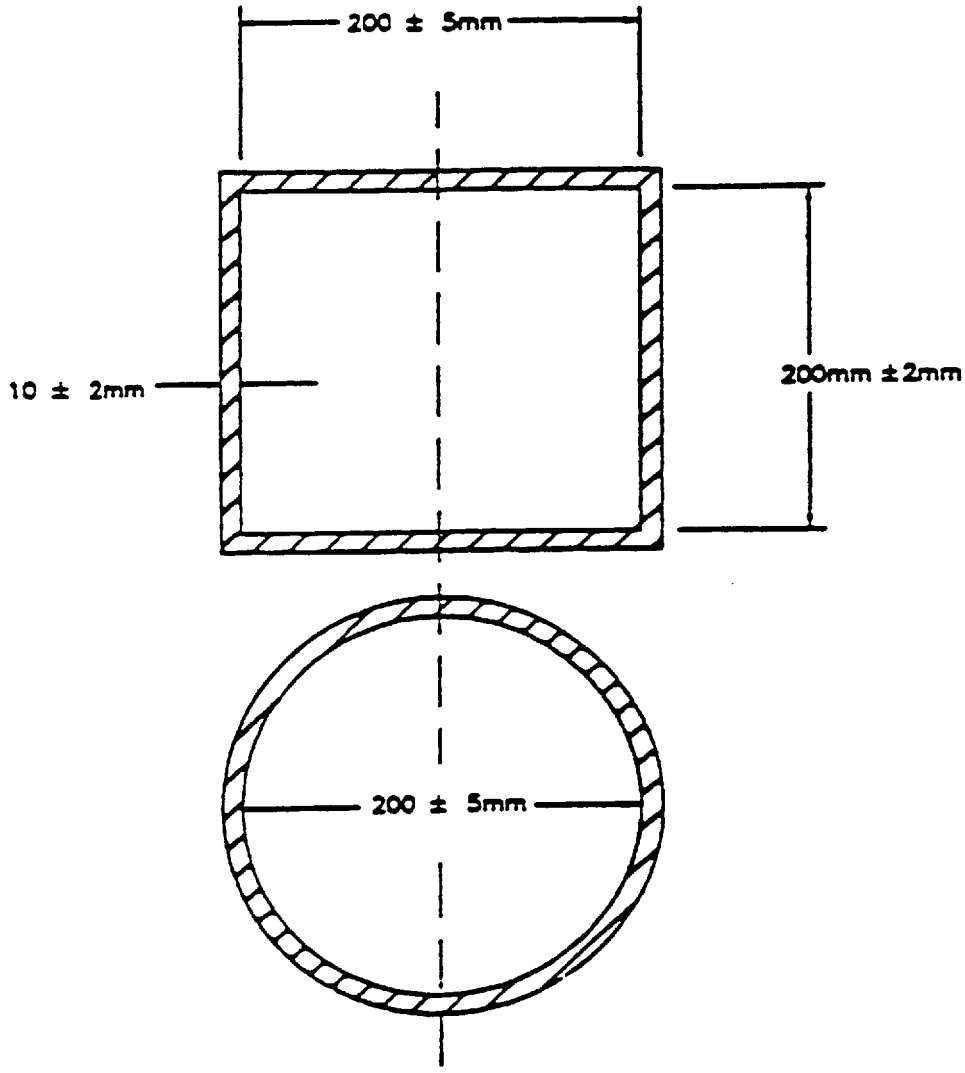


Figure 5-3
VOLUME SENSITIVITY CYLINDRICAL PHANTOM (ACRYLIC)

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Measure the total elapsed time to complete the required 360° SPECT acquisition. Also measure and sum the counts from all the projection images to determine the total counts detected in this total elapsed time.

5.2.4 Calculations and Analysis

Calculate the average counts per minute for the SPECT acquisition (A) by dividing the total counts imaged by the total elapsed time.

Calculate the source activity concentration (B_c) at time T halfway through the 360° SPECT acquisition by applying the proper source decay correction factor for the radionuclide used.

The system volume sensitivity (SVS) is then:

$$SVS = \frac{A \text{ (cts / min)}}{B_c \text{ (kBq / cm}^3\text{)}}$$

The volume sensitivity per axial centimeter, VSAC, is then determined by dividing the SVS by the axial length of the cylindrical source (i.e., 20 cm).

$$VSAC = \frac{SVS}{Length}$$

If the total length of the source cannot be used to obtain the volume sensitivity measurement, the actual length used must be stated along with the results.

5.2.5 Reporting

As a class standard, report the volume sensitivity per axial centimeter (VSAC) in counts per minute per thousand Becquerel per square centimeter (cts/min/kBq/cm^2) for each radionuclide and collimator type. If no radionuclide is reported, than Tc-99m is assumed. Also state the method of acquisition (continuous, step and shoot or other).

5.3 RECONSTRUCTED IMAGE UNIFORMITY

A procedure for quantifying the reconstructed flood field uniformity is not available at this time for incorporation into this Standards Publication. Reconstructed flood field uniformity should be recognized as an essential element in specifying the performance of SPECT systems. Therefore, a standard procedure for this measurement is being pursued and will be issued as a revision to this Standards Publication as soon as feasible.

5.3.1 Rationale for Reconstructed Image Uniformity

Assessment of the reconstructed flood field uniformity of a system is essential for evaluating the performance of a SPECT system. Visualization of artifacts, or structured noise, could have a large detrimental effect on clinical imaging. Patterned non-uniformities can be easily visualized even in the presence of unstructured noise of a much larger variance. Patterned non-uniformities superimposed over a large gradient in reconstructed values due to attenuation are also easily visualized.

For these reasons, simple quantification techniques are incapable of providing an accurate correlate to visual perception. Complex quantitative measures, such as examining the power contained in certain spatial frequency ranges, which might correspond to the frequencies of patterned artifacts without being dominated by random variations, are being investigated. Such techniques will be dependent on the reconstruction filtering and total counts. No acceptable quantitative measure of reconstructed image uniformity is yet available, given the necessity that such measure be both an accurate predictor of visual perception and robust over a reasonable range of operating parameters. Therefore, a visual assessment of reconstructed uniformity is recommended at this time.

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Section 6
SINGLE CRYSTAL SCINTILLATION CAMERA TEST METHODS FOR WHOLE BODY IMAGING: CLASS STANDARD

6.I SYSTEM SPATIAL RESOLUTION WITHOUT SCATTER

System spatial resolution without scatter shall be measured parallel and perpendicular to the direction of motion, and expressed as full width at half maximum (FWHM) and full width at tenth maximum (FWTM) of the line spread function. The measurement shall be reported as a class standard.

6.1.1 Test Conditions

The radionuclide to be employed for this measurement shall be Tc-99m. Any other radionuclide(s) employed shall be separately reported. The activity of the source shall be adjusted to yield a count rate between 10,000 and 20,000 cps, through a 20% energy window, with two capillary tubes in the detector field of view. The camera shall be equipped with a collimator.

6.1.2 Test Equipment

The sources shall consist of two capillary tubes, each having an inside diameter less than or equal to 1.0 mm and a length equal to the width of the scanned field of view perpendicular to the direction of motion. Sources shall be placed on the whole body scanning table, parallel to the plane of the detector.

6.1.2.1 RESOLUTION PARALLEL TO DIRECTION OF MOTION

One capillary tube shall be placed at the center of the scanned field of view, perpendicular to the direction of motion to within 1 mm. The second source shall be placed parallel to the first one, at a distance of 100 mm, as shown in Figure 6-1.

6.1.2.2 RESOLUTION PERPENDICULAR TO DIRECTION OF MOTION

One capillary tube shall be placed at the center of the scanned field of view, parallel to the direction of motion to within 1 mm. The second source shall be placed parallel to the first one, at a distance of 100 mm, as shown in Figure 6-2.

6.1.3 Measurement Procedure

a. Scan speed

The scan speed shall be in the range recommended for clinical use.

b. Camera position

Scans shall be performed both above and below the table for the two source orientations as described in Section 6.1.2. The camera shall be positioned at a distance of 100 millimeters from the sources to the face of the collimator.

c. Digital resolution

The digital resolution perpendicular to the tubes shall be no less than 0.25 of the FWHM of the system resolution of the collimator being used. The digital resolution parallel to the tubes shall be no less than 25 mm and no more than 30 mm.

6.1.4 Calculations and Analysis

The average millimeters/pixel shall be calculated from the known line spacing. This calculation shall be done separately, parallel and perpendicular to the direction of the motion.

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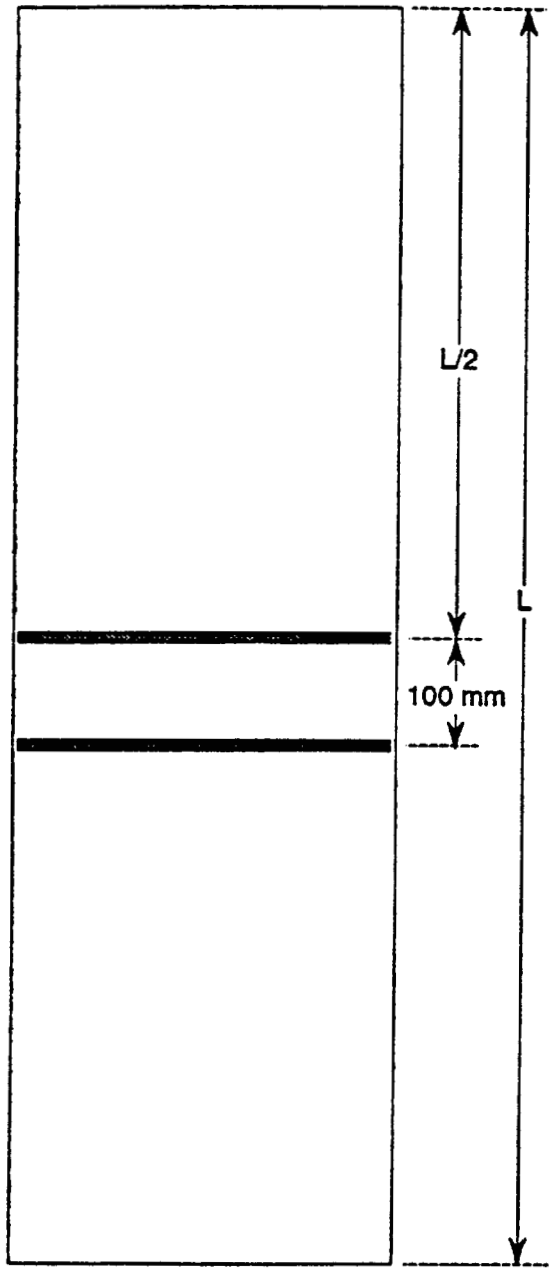


Figure 6-1
SOURCE POSITION FOR RESOLUTION MEASUREMENT PARALLEL TO THE DIRECTION OF MOTION (not to scale)

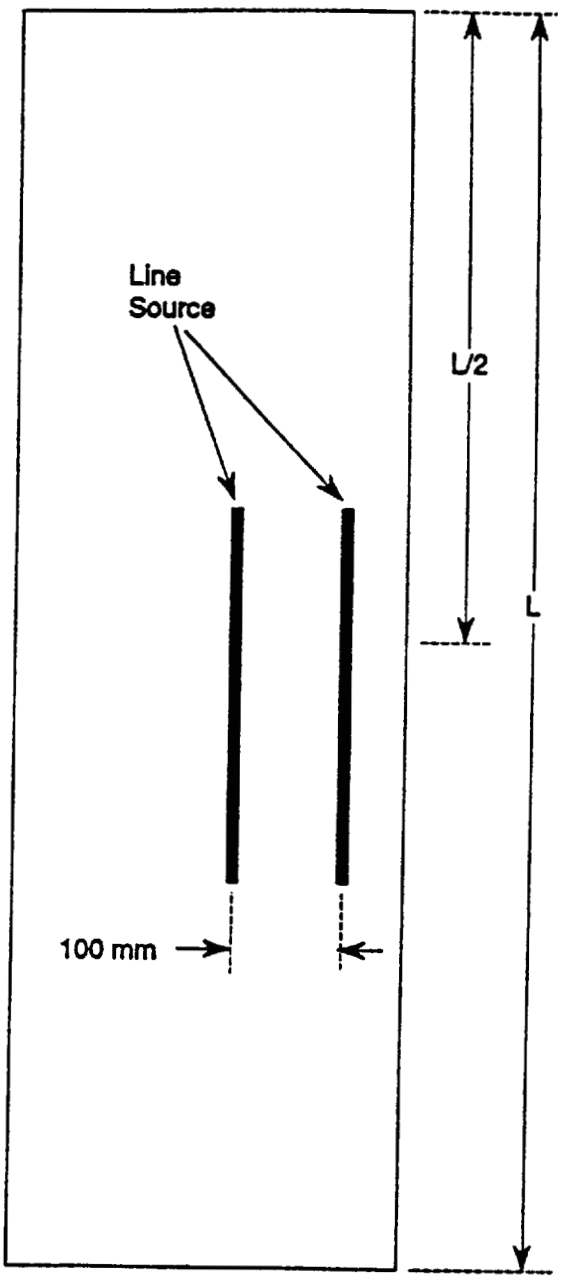


Figure 6-2
SOURCE POSITION FOR RESOLUTION MEASUREMENT PERPENDICULAR TO THE DIRECTION OF MOTION (not to scale)

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The FWHM and FWTM shall be calculated in each segment of the central capillary tube, using the method of Section 2.1.4. The values of the FWHM and FWTM shall be averaged separately for the tubes parallel and perpendicular to the direction of motion.

6.1.5 Reporting

Average FWHM and FWTM shall be reported as class standards. The reported values shall be the average of the measurements above and below the table. Parallel and perpendicular resolution shall be reported separately.

The collimator and scan speed used in performing the measurement shall be reported.

6.1.6 Rationale

The performance of whole body scanning systems depends not only on the intrinsic and system performance of the camera, but also on the performance and alignment of the scanning mechanism. The tests are aimed at measuring the performance of these aspects of the system.

6.1.6.1 SYSTEM SPATIAL RESOLUTION WITHOUT SCATTER

Most problems associated with whole body scanning systems will affect the spatial resolution. Resolutions parallel and perpendicular to the direction of motion are reported separately, as they are controlled by different mechanisms. The resolution parallel to the direction of motion, measured with line sources perpendicular to that direction, is affected by the motion control, camera scale calibration and collimator quality. The perpendicular resolution, measured with line sources parallel to the direction of motion, is affected primarily by the mechanical alignment of the camera and the table.

6.1.6.2 COUNT RATE LIMITS

The test conditions in Section 6.1.1 specify a count range of 10,000 to 20,000 cps. The rationale for specifying a lower limit, as opposed to most other tests, is to assure sufficient statistics in the acquired data, while maintaining normal scanning speeds. As an example, with a count rate of 10,000 cps, a field of view of 40 x 40 cm, a FWHM of 12 mm, a speed of 10 cm per minute, and an acquisition matrix of 1024 x 256 pixels, the number of counts in the peak of the line spread function will be approximately 50,000 counts.

6.2 UNIFORMITY ASSESSMENT OF WHOLE BODY SCANNING SYSTEMS

The uniformity of whole body scanning systems is dependent on many factors, including the drive mechanism, system calibration, collimator uniformity and shape. A quantitative measurement of this uniformity is not practical for several reasons. The statistics required for a quantitative assessment of uniformity would be difficult to acquire with clinically relevant scan speed. Typical causes for non-uniformities are irregular motion or jitter, which would cause artifacts that are easily perceived by the naked eye, but are difficult to quantitate in a meaningful way.

An effective qualitative assessment of the system uniformity can be achieved by attaching a sheet source to the collimators, and performing a whole body scan. Clinical scan speeds should be used. Visual inspection of the image will highlight most non-uniformities.

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Section 7
MULTIPLE CRYSTAL SCINTILLATION CAMERA TEST METHODS: PERFORMANCE STANDARD

7.1 INTRINSIC SPATIAL RESOLUTION

The concept of intrinsic spatial resolution as defined for single crystal cameras is not analogous, nor directly applicable to that of multiple crystal cameras. Overall system spatial resolution is described in Section 8.5.

7.2 INTRINSIC SPATIAL LINEARITY

The concept of intrinsic spatial linearity as defined for single crystal cameras is not analogous, nor directly applicable to that of multiple crystal cameras.

7.3 INTRINSIC ENERGY RESOLUTION

Intrinsic energy resolution shall be measured as a performance standard and expressed as the ratio of the photopeak FWHM to the photopeak center energy, given as a percentage.

7.3.1 Test Conditions

The radionuclide employed for this test shall be Tc-99m. A source holder which shields the source from the walls, ceiling and personnel without restricting the gamma flux from the source to the camera (as shown in Figure 2-1) shall be employed. The integral count rate shall not exceed 300,000 cps through a 115 keV to 160 keV energy window.

7.3.2 Test Equipment

The test equipment shall include the means to digitize the energy spectrum with a channel depth of at least 1,000 counts, for each detector in the n detector array, and a digital resolution of less than or equal to 0.05 FWHM of Tc-99m photopeak.

7.3.3 Measurement Procedure

The radionuclide shall be a Tc-99m point source centered at least five times the largest linear dimension of the UFOV above the detector. A second radionuclide, Co-57, shall be employed as a reference in order to determine the keV per channel calibration factor. The spectra for Tc-99m and Co-57 shall be separately stored for each individual detector. At least 1,000 counts shall be stored in the peak channel of each spectra measurement.

7.3.4 Calculations and Analysis

The spectra from individual detectors for each radionuclide shall be summed. For each radionuclide the summed spectra photopeak location shall be determined as the average of the linearly interpolated half height channel values, calculated for each side of the photopeak (see Figure 2-3).

The difference between the two photopeak locations in channel numbers should correspond to 18.4 keV, which is the difference between the 140.5 keV of the Tc-99m photopeak center energy and the 122.1 keV of the Co-57 photopeak center energy. The intrinsic energy resolution shall be calculated from the Tc-99m summed spectrum. The FWHM in channel numbers shall be determined from the linearly interpolated half height channel values and calculated for each side of the Tc-99m photopeak. This value shall be multiplied by the keV's per channel calibration factor, divided by 140.5 keV corresponding to the Tc-99m photopeak center energy, and multiplied by 100 in order to obtain the value as a percentage.

7.3.5 Reporting

The intrinsic energy resolution, calculated from the sum of the spectra for individual detectors, for a Tc-99m radionuclide shall be reported as a performance standard and expressed as a percentage.

7.4 SYSTEM UNIFORMITY

As a performance standard, the system uniformity shall be measured with a parallel hole collimator. The system uniformity is the response of the system, with a collimator, to a uniform field of

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radiation from a uniform sheet or flood source. Two different uniformity parameters shall be determined: integral uniformity and differential uniformity. Integral uniformity is a measure of the maximum detector count deviation in the UFOV. Differential uniformity is a measure of the maximum deviation over a limited range designed around the individual detector size.

7.4.1 Test Conditions

The radionuclide used to measure system uniformity shall be Co-57. Any other radionuclide shall be reported separately. The count rate shall not exceed 500,000 cps through a 105 keV to 150 keV window. The status of detector corrections used shall be stated with the results.

7.4.2 Test Equipment

The test equipment required for this measurement consists of a Co-57 flood source large enough to cover the UFOV.

7.4.3 Measurement Procedure

The system uniformity shall be measured for each collimator supplied. The uniformity data shall be stored in a matrix having as many points as there are detector elements. Each uniformity measurement shall acquire a minimum of 30,000 counts in the maximum pixel.

The flood source shall be placed 5 centimeters from the face of the collimator and centered so that all collimator holes are covered by the source.

7.4.4 Calculations and Analysis

System flood field uniformity shall be measured and expressed as "integral uniformity" (maximum deviation) and "differential uniformity" (maximum rate of change over adjacent detectors). Both shall be measured using all pixel in the UFOV and expressed as ± percentage values.

An array of flood field correction factors shall be calculated for each collimator from an image acquired with a uniform source and containing a minimum of 30,000 counts in the maximum pixel location. The correction factor for each pixel is the fraction formed by the ratio C_{pixel}/C_{max} where C_{pixel} is the count in the pixel and C_{max} is the maximum pixel count.

7.4.4.1 INTEGRAL UNIFORMITY

For pixels within the UFOV the maximum and minimum values shall be identified. The difference between the maximum and minimum is divided by the sum of these two values and multiplied by 100 percent. The formula for integral uniformity is defined in Section 2.4.4 and is restated here for convenience.

Integral Uniformity = ± 100% ((Max - Min) / (Max + Min))

The correction factors shall then be applied to the uniformity data and the corrected integral uniformity shall be calculated.

7.4.4.2 DIFFERENTIAL UNIFORMITY

For all pixels, within the UFOV, the largest difference between any two pixel within a set of three contiguous pixels in a row or column shall be calculated. The calculation shall be done for the X and for the Y directions independently and the maximum change expressed as a percentage using the formula defined in Section 2.4.4 and restated here for convenience.

Differential Uniformity = ± 100% ((Max - Min) / (Max + Min))

The corrected data is treated as a number of rows (X slices) and columns (Y slices). Each slice is processed by starting the beginning pixel for the respective direction. A set of three contiguous pixels is examined to find the maximum and minimum pixels. The percent uniformity is calculated using these values. The next set of three contiguous pixels are analyzed by stepping forward one pixel and again determining the percent uniformity. This is repeated until the outermost pixel is reached for the field of view. the maximum percent uniformity is found in the slice. The process is then repeated for all the slices in the field of view. The maximum for all slices is found.

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The correction factors shall then be applied to the uniformity data and the corrected integral uniformity is then calculated.

7.4.5 Reporting

The result is reported as the performance Standard and expressed as the percentage integral and differential uniformity within the UFOV for each collimator supplied with the system.

The results are reported as uncorrected uniformity and also as corrected uniformity.

7.5 MULTIPLE WINDOW SPATIAL REGISTRATION

Multiple window spatial registration shall be measured and reported as a performance standard. Multiple window spatial registration is a measure of the camera's ability to accurately position photons of different energies when imaged through different photopeak energy windows. Measurements shall be made at nine specified points on the scintillation camera.

7.5.1 Test Conditions

The radionuclides employed to measure multiple window spatial registration shall be Am-241 and Tc-99m. The count rate shall not exceed 50,000 cps through a 40 keV to 70 keV photopeak energy window for Am-241 and 115 keV to 160 keV for Tc-99m.

7.5.2 Test Equipment

A lead-lined source holder shall collimate the Am-241 or Tc-99m source through a circular tunnel in the lead. This circular tunnel shall be 5 mm in diameter and 25 mm in length. The high resolution collimator shall be used.

7.5.3 Measurement Procedure

Images shall be acquired using the above described collimated Am-241 and Tc-99m sources located at nine specific points on a plane 10 cm from the surface of the collimated camera and using the camera's scanning capabilities. These nine points shall be the central point, four points on the X axis and four points on the Y axis. The off central points shall be located 0.4 times and 0.8 times the distance from the central point to the edge of the UFOV of the camera along the respective axes. Separate images of the collimated Am-241 and Tc-99m sources shall be acquired in the scanning mode of the camera. These images shall be stored in a matrix size of 80 by 80. At least 1,000 counts shall be acquired in the peak pixel for each photopeak image.

7.5.4 Calculations and Analysis

The displacement of the count centroids from each other in the X and Y directions shall be determined for each measurement point's photopeak images. A square region of interest (ROI) centered on the maximum count pixel associated with each photopeak image shall be used to analyze the individual photopeak images. The pixel dimensions of the square ROI shall be approximately four times the FWHM of the image count profile to be analyzed. Each image shall be integrated in the Y direction to determine the X count profile and integrated in the X direction to determine the Y count profile. The centroid of counts in the X and Y directions shall be determined for each image for the directions's count profile by the method described in Section 2.5.4 and restated here for convenience. The maximum difference in position of the centroid of counts acquired from each photopeak shall be determined. The largest pixel displacement shall then be converted to millimeters using an accurate millimeter per pixel calibration determined from the physical size of the individual crystals in the multicrystal detector array.

7.5.4.1 METHOD FOR CENTROID OF COUNT DETERMINATION

The center of counts in the X and Y directions for each of the photopeak count profiles shall be determined as follows. Find the maximum count pixel in the integrated X or Y profile and calculate the centroid of counts using the following formula:

$$L_j = \sum_{i=1}^{n} (X_i * Ci) / \sum_{i=1}^{n} Ci$$

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Where:

L_j = calculated centroid location for energy window j, where j can equal 1 or 2.
X_i = X or Y profile pixel at the i-th location
Ci = counts at the X_i or Y_i location.

$\sum_{i=1}^{n}$ = sum over an odd number of count profile pixels centered on the maximum count profile pixel. The exact odd number of pixels will depend on the FWHM of the count profile and the pixel size. The minimum number of pixels in this sum shall include both the left and right half maximum counts.

The displacement D_{ij} between energy windows i and j is then :

$$D_{ij} = | L_i - L_j | \text{ where } i = 1 \text{ or } 2 \text{ and } j = 1 \text{ or } 2$$

The maximum displacement is simply the largest D_{ij}

7.5.5 Reporting

The multiple window spatial registration shall be reported as the maximum displacement in either the X or Y direction of the photopeak centroids for the nine points measured. This performance standard shall be reported in millimeters to the nearest tenth of a millimeter.

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Section 8
MULTIPLE CRYSTAL SCINTILLATION CAMERA TEST METHODS: CLASS STANDARDS

8.1 INTRINSIC COUNT RATE PERFORMANCE IN AIR

Decaying source method shall be used to determine count rate performance. Two parameters shall be measured and reported: observed count rate for a 20% count loss and a maximum count rate. Both parameters shall be measured without induced scatter. The curve of observed vs input count rate shall be provided.

8.1.1 Test Conditions

The radionuclide employed for the test shall be Tc-99m. Any other radionuclide(s) employed shall be separately reported.

The energy window shall be from 115 keV to 160 keV. The camera shall be tested in normal mode per Section 1.3.3.

8.1.2 Test Equipment

A camera under test shall not have a collimator installed. The source shall be placed within a lead container as shown in Figure 3-1. The open side (facing the camera crystal) shall be covered by 6 mm of copper plates. The source intensity shall be such that it produces an input count rate which is larger than the count rate required to cause foldover in the observed count rate.

8.1.3 Measurement Procedure

Determine the background count, N_{bkg}. The suggested time for this determination is 10 minutes. The lead holder with the source shall be placed in a suitable position in front of the detector. The source holder shall be positioned so that the collimated cone of radiation is centered within the UFOV and that the irradiated area of the crystal extends fully across the smaller dimension of the UFOV. Care must be taken to minimize scatter.

The start (t_i) and elapse time (Δt_i) of the measurement shall be recorded for each data point, where (i) is the number of the data point.

The time shall be measured relative to the start of acquisition time of the measurement of the first data point. For each data point (Ci), at least 100,000 counts shall be collected. Data should be acquired for 10 seconds or 100,000 counts whichever is longer.

The measurement should be performed so that the points are taken as soon as the observed count rate changes by 10,000 cps from the previous measured point. The last (n-th) point taken should be measured when an observed count rate drops below 15,000 cps.

8.1.4 Calculations and Analysis

The observed count rate (OCR_i) shall be determined for each data point according to the following formula:

$$OCR_i = (Ci - N_{bkg} * \Delta t_i)$$

Equation 8.1.4-1

where all measurement times are in seconds, or fractions thereof.

The input count rate (ICR_i) for each data point shall be calculated according to formula (2) defined in Section 3.1.4 and restated here as:

$$ICR_i = OCR_n * \exp((t_n - t_i) / 21672 * \ln(2))$$

Equation 8.1.4-2

Where 21672 represents the number of seconds in one half life of Tc-99m.

The observed count rate at 20% loss shall be determined by linear interpolation between the two closest points to the equation

$$OCR_i = 0.8 * ICR_i$$

Equation 8.1.4-3

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Explanation

The purpose of Equation 8.1.4-1 is to correct the measurements for background. Scaling to the beginning of the measurement as defined by Equation 3.1.4-1 is not required because the error produced in counting to 100,000 counts at a count rate of 15,000 cps is not significant.

8.1.5 Reporting

The maximum observed count rate, the observed count rate at 20% loss, and the curve of observed count rate vs the input count rate shall be reported as class standards.

8.1.6 Technical Note

This test is very time consuming, approximately 2 days. An alternative method is to use carefully calibrated copper sheets as discussed in the following articles:

1. *A New Approach to NEMA Scintillation Camera Count Rate Curve Determination,* by E. M. Geldenhuys et al. JNM Vol. 29, No. 4, April 1988 p. 538.

2. *Spectral Changes Affect Intrinsic Count Rate Tests,* by Stephen I. Breem / Trevor D. Cradduck, JNM Vol. 31, No. 12, December 1990, p. 2074.

Traceability of this method to above standards must be demonstrated.

8.2 SYSTEM COUNT RATE PERFORMANCE WITH SCATTER

Decaying source method shall be used to determine the count rate performance. Two parameters shall be measured and reported: observed count rate for a 20% count loss and a maximum count rate. Both parameters shall be measured with scatter. The curve of observed vs input count rate shall be provided.

8.2.1 Test Conditions

The radionuclide employed for the test shall be Tc-99m. Any other radionuclide(s) employed shall be separately reported. The energy window shall be from 115 keV to 160 keV. The camera shall be tested in a normal mode per Section 1.3.3.

8.2.2 Test Equipment

A camera under test shall have a low energy collimator of highest efficiency mounted. The source shall be in a liquid solution filling a plastic cylindrical phantom with dimensions shown in Figure 3-2. The source intensity shall be such that it produces an input count rate which is larger than the count rate required to cause foldover in the observed count rate.

8.2.3 Measurement Procedure

The detector shall be positioned to view the 50 mm thick plastic base of the phantom. The distance between the phantom and the face of the collimator shall not be more than 20 mm. The phantom shall be centered within the UFOV.

Prior to beginning the measurement, the background count rate, N_{bkg}, shall be determined. The start time (t_i) and elapsed time (Δt_i) of the measurement shall be recorded for each data point, where (i) is the number of the data point.

The time shall be measured relative to the start of acquisition time of the measurement of the first data point. For each data point (Ci), at least 100,000 counts shall be collected. Data shall be acquired for 10 seconds or 100,000 counts whichever is longer.

The measurement should be performed so that the points are taken as soon as the observed count rate changes by 10,000 cps from the previous measured point. The last (n-th) point taken should be measured when an observed count rate drops below 15,000 cps.

8.2.4 Calculations and Analysis

The observed count rate (OCR_i) shall be determined for each data point according to the following formula:

$$OCR_i = (Ci - N_{bkg} * \Delta t_i)$$

Equation 8.2.4-1

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where all measurement times are in seconds, or fractions thereof.

The input count rate (ICR_i) for each data point shall be calculated according to formula (2) defined in Section 3.1.4 and restated here as:

$$ICR_i = OCR_n * \exp((t_n - t_i) / 21672 * \ln(2))$$

Equation 8.2.4-2

Where 21672 represents the number of seconds in one half life of Tc-99m.

The observed count rate at 20% loss shall be determined by linear interpolation between the two closest points to the equation

$$OCR_i = 0.8 * ICR_i$$

Equation 8.2.4-3

Explanation

The purpose of Equation 8.2.4-1 is to correct the measurements for background. Scaling to the beginning of the measurement as defined by Equation 3.1.4-1 is not required because the error introduced by counting to 100,000 counts at a count rate of 15,000 cps is not significant.

8.2.5 Reporting

The maximum observed count rate, the observed count rate at 20% loss, and the curve of observed count rate, with scatter versus the input count rate shall be reported as class standards.

8.3 INTRINSIC SPATIAL RESOLUTION AT 75,000 COUNTS PER SECOND

The concept of intrinsic spatial resolution as defined for single crystal cameras is not analogous, nor directly applicable to that of multicrystal cameras. Overall system spatial resolution is described in Section 8.5.

8.4 SYSTEM FLOOD FIELD UNIFORMITY AT 400,000 COUNTS PER SECOND

Intrinsic flood field uniformity shall be measured at 400,000 counts per second and the integral and differential uniformity for the UFOV shall be reported following the procedures and reporting of Section 7.4.

8.5 SYSTEM SPATIAL RESOLUTION WITH AND WITHOUT SCATTER

As a class standard, the system spatial resolution with and without scatter shall be measured and expressed as FWHM and FWTM of the line spread function.

8.5.1 Test Conditions

The radionuclide employed for this measurement shall be Tc-99m. The count rate shall not exceed 300,000 cps through a 115 keV to 160 keV window.

8.5.2 Test Equipment

The test equipment required for these measurements shall consist of two capillary tubes with an inside diameter of less than or equal to 1.0 mm and a length greater than 30 mm. Also, acrylic scattering blocks, the size of the UFOV of the system to be measured and 100 and 50 mm thick, are required for the "with scatter" measurements. The required acrylic scattering thickness may be assembled from thinner pieces but must still cover than entire UFOV. Also required is a method of moving the tubes in 1.0 mm steps over a distance of 10 mm in both the X and the Y direction.

8.5.3 Measurement Procedure

The capillary tubes shall be filled with the desired radionuclide. One of these tubes shall be positioned 100 mm from the face of the system collimator and along the axis of measurement, X or Y.

At least 10,000 counts shall be collected in the peak point of each line spread function. The measurement shall be made by displacing the capillary tube, and the scattering medium if used, in 1 mm steps for a total of 10 millimeters. The data shall be stored in a 200 by 20 pixel array.

Measure the FWHM and FWTM in pixels of all the line spread functions that fall within the UFOV,

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first in the X direction and then in the Y direction, using the method of Section 2.1.4.

A second measurement for each axis shall be performed with the second capillary tube also positioned 100 mm from the face of the collimator and 50 mm away from, and parallel to, the first tube. This measurement shall be used for calibration of the millimeters per pixel only. The single capillary tube measurement shall then be repeated using the acrylic scattering blocks. The capillary tube remains 100 mm from the face of the collimator and sandwiched between the 100 mm thick forward scattering block and the 50 mm back scattering block.

8.5.4 Calculations and Analysis

Convert the FWHM and FWTM measurements from pixels to millimeters using the measured millimeter per pixel calibration factor.

Average the appropriate "without scatter" measurements in both the X and Y directions. Average the appropriate "with scatter" X and Y direction measurements together.

8.5.5 Reporting

System spatial resolution, with and without scatter, shall be reported as FWHM and FWTM within the UFOV This shall be reported as the class standard. The collimator and the radionuclide employed shall also be reported.

8.6 SYSTEM PLANAR SENSITIVITY

The planar sensitivity is the sensitivity in one acquisition plane to a specific planar source placed parallel to that plane. Planar sensitivity measurements are dependent on collimator type, window width, gamma energy, source configuration and other factors.

The planar sensitivity of the system shall be measured for each collimator type and reported in counts/min/MBq or counts/min/μCi.

8.6.1 Test Conditions

The radionuclides employed for these measurements shall be those for which the collimators are designed. The count rate shall not exceed 75,000 cps through a 115 keV to 160 keV window.

8.6.2 Test Equipment

The test equipment required for this measurement consists of a 1 to 5 cc volume plastic syringe, a calibrated dose calibrator, and a 100 mm diameter flat plastic dish (petri dish).

8.6.3 Measurement procedure

The source activity inside the plastic syringe shall be accurately measured using a dose calibrator. This source shall then be dispersed from the syringe into an approximately 3 mm deep water solution in a 100 mm diameter flat plastic dish.

The empty syringe shall be re-measured in the dose calibrator and the reading subtracted from the original reading to obtain the amount of activity in the dish at the time of preparation.

Calibration methods shall be those set forth in the NRC Regulatory Guide 10.8, or alternatively NIST traceable calibration sources shall be used as references with appropriate half life corrections. The prepared dish source shall be placed near the center of the Field of View and in a plane 100 mm from the face of the collimator. No scatter material shall be present to affect this measurement.

Accurately determine the counts per minute recorded by the imaging system. In this context "counts" shall be defined as interactions in the crystal that fall within the energy window: therefore, field uniformity correction devices that alter the number of counts must be disabled.

8.6.4 Calculations and Analysis

Divide the determined number of counts per minute by the activity in MBq or μCi at the time of the measurement to get the Planar Sensitivity of the system. (1 micro Curie = .037 million Becquerel.)

8.6.5 Reporting

Report the planar sensitivity for the system in counts min/MBq or counts/min/μCi. It shall be reported

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as a class standard. The radionuclide and collimator shall be stated.

8.7 DETECTOR SHIELDING

Shield leakage is the penetration of the shielding by sources placed 10 centimeters from the detector housing and reported as a leakage in counts/minute/MBq.

8.7.1 Test Conditions

Shield leakage shall be reported for Tc-99m and for a source specified with the maximum design energy of the camera. The counting rate, when the source is placed 10 centimeters in front of the collimator of specified energy, shall be less than 10,000 cps through a 115 keV to 160 keV energy window. The counting rate through the shielding shall be measured while the specified collimator is mounted to the camera.

8.7.2 Test Equipment

The test equipment for this measurement consists of a source holder shown in Figure 2-4 and a collimator of the specified energy. The vial containing the source shall be completely filled with liquid.

8.7.3 Measurement Procedure

The source shall be placed in the source holder. The source shall be imaged through the collimator of specified energy and the counting rate recorded after counting at least 10,000 counts and recording the length of time.

The source shall be moved around the detector at a distance of 10 centimeters from the detector. Move around the sides and back of the detector to find the location of maximum counts. The source shall be counted at this location until the leakage counts, plus background counts, are three times the square root of the background counts.

Note that care must be taken to avoid Compton scatter from the source into the face of the collimator while measuring shield leakage.

8.7.4 Calculations and Analysis

The percent shielding leakage shall be calculated and reported as a number:

$$\text{Shielding Leakage} = \frac{\text{Max Shield Count Rate}}{\text{Collimator Count Rate}} * 100$$

8.7.5 Reporting

The shield leakage shall be reported as a class standard for Tc-99m and the highest energy radionuclide for which the detector is designed. The collimator used for the measurement shall be specified.

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NEMA STANDARDIZATION BACKGROUND

The purpose of NEMA standards, their classification, and status are set forth in certain clauses of the NEMA *Standardization Policies and Procedures* manual and are referenced below:

Purpose of Standards

National Electrical Manufacturers Association Standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting and obtaining the proper product for their particular needs. Existence of a National Electrical Manufacturers Association Standard does not in any respect preclude any member or nonmember from manufacturing or selling products not conforming to the standard.

Definition of a Standard

A standard of the National Electrical Manufacturers Association defines a product, process, or procedure with reference to one or more of the following: nomenclature, composition, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

(Standardization Policies and Procedures, p. 1)

Dimensions

Where dimensions are given for interchangeability purposes, alternate dimensions satisfying the other provisions of the Standards Publication may be capable of otherwise equivalent performance.

(Standardization Policies and Procedures, p. 6)

Categories of Standards

National Electrical Manufacturers Association Standards are of three classes, which have received the affirmative vote of at least two-thirds of the Subdivision votes cast in the affirmative or negative:

1. NEMA Standard, which relates to a product, process, or procedure commercially standardized and subject to repetitive manufacture.
2. Suggested Standard for Future Design, which may not have been regularly applied to a commercial product, but which suggests a sound engineering approach to future development.
3. Adoptive Standard, which is adopted in whole or in part from the standards of another organization, either domestic, regional, or international.

(Standardization Policies and Procedures, pp. 5)

Authorized Engineering Information

Authorized Engineering Information consists of explanatory data and other engineering information of an informative character not falling within the classification of NEMA Standard or Suggested Standard for Future Design, which standard has received the affirmative vote of at least two-thirds of the Subdivision votes cast in the affirmative or negative.

(Standardization Policies and Procedures, pp. 5)

Identification of Status

Standards in NEMA Standards Publications are identified as "NEMA Standard," "Suggested Standard for Future Design," or "Adoptive Standard." These indicate the status of the standard. A statement incorporating the auxiliary verb "shall" indicates that compliance with a requirement is mandatory for compliance with the standard. These classes of standards are identified in the foreword or throughout the text.

The material identified as "Authorized Engineering Information" is designated similarly. Statements incorporating other auxiliary verbs such as "should," "may," etc. refer to the authorized engineering information and not to procedures required for compliance with the standard.

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