NU 1-86 6470247 0003084 4
F-87-31

STANDARDS PUBLICATION / NO. NU 1

nema

Performance Measurements of Scintillation Cameras

NEMA

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION ■ 2101 L STREET, N.W., WASHINGTON, D.C. 20037

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

NEMA NU 1-1986

NU 1

PERFORMANCE MEASUREMENTS OF SCINTILLATION CAMERAS

Published by

National Electrical Manufacturers Association
2101 L Street, NW
Washington, DC 20037
(202) 457-8400

© 1986 by National Electrical Manufacturers Association

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS Not for Resale

PERFORMANCE MEASUREMENTS OF SCINTILLATION CAMERAS

TABLE OF CONTENTS

Page

FOREWORD i
PURPOSE i
SCOPE ii

Section 1 REFERENCED PUBLICATIONS AND DEFINITIONS
General 1
Referenced Standards 1
General Definitions 1

Section 2 SINGLE CRYSTAL SCINTILLATION CAMERA TEST METHODS
Definitions 3
General 3
Reported Values 3
Additional Tests 3
Correction 3
Traceability 3
Test Equipment and Minimum Instrumentation Requirements 3
Multichannel Analyzer (MCA) 3
Additional Test Equipment 3
Tests 3
Intrinsic Spatial Resolution 3
Intrinsic Spatial Linearity 7
Intrinsic Energy Resolution 9
Intrinsic Flood Field Uniformity 9
Point Source Sensitivity Variation 11
Intrinsic Count Rate Performance 11
Multiple Window Spatial Registration 12
System Spatial Resolution With and Without Scatter 13
System Sensitivity 14
System Count Rate Performance With Scatter 14

Section 3 MULTIPLE CRYSTAL SCINTILLATION CAMERA TEST METHODS
Definitions 17
General 17
Reported Values 17
Additional Tests 17
Correction Devices 17
Traceability 17
Test Equipment 17
Test Equipment Performance 17
Minimum Test Equipment Requirements 17
Tests 17
Intrinsic Spatial Resolution 17
Intrinsic Spatial Linearity 17
Intrinsic Energy Resolution 17
System Flood Field Uniformity 18

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

TABLE OF CONTENTS *(cont'd.)*

Page

Section 3 MULTIPLE CRYSTAL SCINTILLATION CAMERA TEST METHODS *(continued)*

Multiple Window Spatial Registration 22
System Spatial Resolution With and Without Scatter 23
System Sensitivity 23
Extrinsic Count Rate Performance With Scatter 24

Section 4 SCINTILLATION CAMERA BASED SINGLE PHOTON EMISSION COMPUTED TOMOGRAPHY (SPECT) PERFORMANCE MEASUREMENT STANDARDS

Definitions 26
General 26
Test Equipment 26
Tests 26
Angular Variation of Flood Field Uniformity and Sensitivity 26
Angular Variation of Spatial Position 27
Reconstructed System Spatial Resolution 27
Reconstructed Image Uniformity 28

Section 5 TRACEABILITY DATA

Introduction 30
General 30
Intrinsic Spatial Resolution 30
Intrinsic Energy Resolution 30
Intrinsic Flood Field Uniformity 30
Intrinsic Spatial Linearity 30
Multiple Window Spatial Registration 30
Tests Duplicated by User 30

Section 6 TRACEABILITY DATA (MULTICRYSTAL CAMERAS)

Introduction 31
General 31
System Spatial Resolution 31
Intrinsic Energy Resolution 31
System Flood Field Uniformity 31
System Spatial Linearity 31
Multiple Window Spatial Registration 31
Tests Duplicated by User 31

Appendix A RATIONALE FOR SINGLE CRYSTAL SCINTILLATION CAMERA TEST METHODS

Background 32
Traceability 32
Rationale for Chosen Measurement Techniques 32

Appendix B RATIONALE FOR MULTIPLE SCINTILLATION CRYSTAL CAMERA TEST METHODS

Background 36
Traceability 36
Rationale for Chosen Measurement Techniques 36

Appendix C RATIONALE FOR SCINTILLATION CAMERA BASED SINGLE PHOTON (SPECT) PERFORMANCE MEASUREMENT STANDARDS

Background 38
Rationale 38
Reconstructed System Spatial Resolution 39
Rationale 39
Discussion 39

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

TABLE OF CONTENTS *(cont'd.)*

Page

Appendix D SPECT SYSTEM PERFORMANCE MEASUREMENT REPORTING FORM..... 40

Appendix E RECONSTRUCTED (RELATIVE IMAGE NOISE) IMAGE UNIFORMITY..... 42

Appendix F COLLIMATOR SENSITIVITY CALIBRATION NOTE..... 43

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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:

Manager, Engineering Department
National Electrical Manufacturers Association
2101 L Street, N.W.
Washington, D.C. 20037

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.

The recommendations of the National Council on Radiation Protection and Measurements (NCRP), relative to radiation safety, should be reviewed and applied.

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 for Performance Measurements of Scintillation Cameras". This standard does not establish minimum performance levels.

Elaborate measurement equipment 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, nonquantitative, or too time consuming. It is due to this equipment and its resulting data for specification reporting purposes, that accurate measurements and test procedures can be written. The concept of traceability, established in Appendix A, A.1.1 and Appendix B, B.1.1 provides the means for relating the manufacturer's performance measurements to acceptance tests.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

SCOPE

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

Intrinsic spatial resolution
Intrinsic spatial linearity
Intrinsic energy resolution
Intrinsic flood field uniformity
Point source sensitivity variation
Intrinsic count rate performance
Multiple window spatial registration
System spatial resolution with and without scatter
System sensitivity
System count rate performance with scatter
System flood field uniformity
System spatial linearity
Extrinsic count rate performance with scatter
Angular variation of flood field uniformity and sensitivity
Angular variation of spatial position
Reconstructed system spatial resolution
Reconstructed image uniformity

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

1. Single crystal scintillation cameras
2. Multiple crystal scintillation cameras
3. Tomographic devices which image a section or reconstruct an image volume, or both.

Exclusions—Types of medical radionuclide devices not included in this standard are:

1. Point, linear, or area imaging devices which require a mechanical means to image an area (e.g., radionuclide scanners)
2. Display and photographic devices
3. Data recording devices
4. Data processing devices
5. Devices which employ physiological data other than radioisotopic distribution
6. Positron coincidence imaging devices

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

PERFORMANCE MEASUREMENTS OF SCINTILLATION CAMERAS

Section 1

REFERENCED PUBLICATIONS AND DEFINITIONS

1.1 GENERAL

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

1.2 REFERENCED PUBLICATIONS

In this publication, reference is made to the standards listed below. Copies are available from the indicated source.

Electronic Industries Association
Engineering Department
2001 Eye St., N.W.
Washington, DC 20006

EIA Standard RS-232-C-1969 *Interface Between Data Terminal Equipment and Data Communication Equipment Employing Serial Binary Data Interchange*

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

NRC Regulatory Guide 10.8, January 1979, Appendix D, Section 2 *Guide for the Preparation of Applications for Medical Programs,* "Methods for Calibration for Dose Calibrator."

The Society of Nuclear Medicine
136 Madison Avenue, 8th Floor
New York, NY 10016

Journal of Nuclear Medicine, Vol. 19, 1978, Lim, C.B., Hoffer, P.B., Rollo, F.D., and Lilien, D.L. "Performance Evaluations of Recent Wide Field Scintillation Gamma Cameras," pp. 942-947.

Journal of Nuclear Medicine, Vol. 19, 1978, Adams, R., Hine, G.J. and Zimmerman, C.D., "Deadtime Measurements in Scintillation Cameras Under Scatter Conditions Simulating Quantitative Nuclear Cardiography," pp. 538-544.

1.3 GENERAL DEFINITIONS

The definitions contained in Section 1 apply to both single and multiple crystal scintillation cameras. Refer to Section 2 for definitions which relate only to single cyrstal scintillation cameras and to Section 3 for definitions which relate only to multiple crystal scintillation cameras.

Analyzer window is a pulse height analyzer (PHA) electronic circuitry which is used to selectively allow only a specified range of gamma energies to be accepted and processed by the scintillation camera. Units are expressed in percent of peak energy. The window is symmetrically positioned about the peak unless otherwise stated.

Class standard is a value(s) which characterizes a specific performance parameter TYPICAL of the given model number or series of scintillation cameras for which it applies. The parameter is of auxiliary interest and is a subset of a measured standard.

Detector is a component of the scintillation camera which is designed to detect incident gamma radiation for the purpose of imaging and counting.

Differential linearity is a term which characterizes the amount of positional distortion or displacement over a known distance with respect to detected gamma rays entering the detector.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

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

Digital resolution is the number of channels or discrete binary values used when converting analog scintillation camera signals to digital signals.

Energy resolution is a term used to characterize the ability of a gamma camera to distinguish between detected gamma radiation of different energies.

Foldover describes the progressive decrease in the observed counting rate with increasing levels of radioactivity that occurs after the maximum count rate capacity of a scintillation camera is exceeded.

Full width at half maximum (FWHM) is the measure of the spread of a point or line spread function measured across locations 50 percent down on each side from the peak amplitude.

Full width at tenth maximum (FWTM) is the measure of the spread of a point or line response function measured across locations 90 percent down on each side from the peak amplitude.

Input count rate is the rate of scintillation events that are accepted by the analyzer window and shall be recorded as the observed count rate if there were no dead time in the system. At counting rates <2500 counts per second, the input count rate is the same as the observed count rate because dead time losses are negligible.

Integral linearity characterizes the positional distortion or displacement in the X and Y coordinates in a scintillation camera image with respect to incident gamma photon absorption events in the detector.

Intrinsic is 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.

Observed count rate refers to the counts per unit time obtained from gamma photons incident on the detector as determined by the scintillation camera's counting electronics, e.g. count rate scaler or meter.

Performance standard represents test measurement specifications that apply to and must be met by every gamma camera.

Photopeak is the characteristic primary radionuclide energy distribution resulting from the collection of total gamma energy absorbed by the detector.

Pixel is an image element used to store images in a digital memory. It represents a known X-Y location and contains count information integrated from that X-Y area.

Scatter is a gamma ray from a source that has lost part of its energy due to its travel and interaction in a medium, such as water and acrylic.

Sensitivity is a term that describes the number of counts per unit of radioactivity viewed by a scintillation camera.

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

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

Standard deviation is the 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 is a term used to describe camera operation with the collimator.

Test pattern is a lead pattern that projects a known shadow of itself when illuminated by gamma rays or a known source configuration, used as a controlled input for measurement of scintillation camera parameters.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Section 2

SINGLE CRYSTAL SCINTILLATION CAMERA TEST METHODS

2.1 DEFINITIONS

The definitions contained in Section 2 apply to only single crystal scintillation cameras. Refer to Section 1 for general definitions which apply to both single and multiple crystal scintillation cameras.

The central field of view (CFOV) is that area defined by scaling all linear dimensions of the UFOV by a factor of 75 percent. The CFOV is centered on the center of the UFOV. The dimensioned figure of the CFOV will be supplied by the manufacturer.

The useful field of view (UFOV) is that area defined by a dimensioned figure supplied by the manufacturer.

2.2 GENERAL

2.2.1 Reported Values

In stating specifications, all reported values shall be labeled as "worst case", "better than", "not to exceed" and the field of view shall be indicated, except where otherwise specified in this document. In the case of Class Standard values, a typical value shall be reported.

2.2.2 Additional Tests

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

2.2.3 Correction

If field uniformity, energy, or linearity correction is employed, all measurements shall be consistently performed with these corrections on or off and the results so indicated.

2.2.4 Traceability

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.

2.3 TEST EQUIPMENT AND MINIMUM INSTRUMENTATION REQUIREMENTS

2.3.1 Multichannel Analyzer (MCA)

A Multichannel Analyzer (MCA) shall be either:

1. A two parameter MCA capable of acquiring up to 1024 × 16 channels, including 64 × 64; or
2. A two parameter MCA capable of acquiring up to 1024 × 1 and 64 × 64 channels. To employ this system for spatial resolution and linearity measurements, it shall be necessary to construct a 30-millimeter wide "slot" mask placed perpendicular to the slits of the slit mask or perpendicular to the capillary tubes. Therefore, it shall be necessary to perform approximately 8 to 16 separate measurements, displacing the "slot" by 30 millimeters on each successive measurement, to acquire the necessary data.

In either of the above two cases, the MCA requires a channel depth of 10,000 counts minimum.

The MCA system shall either be a computer based system or generate a computer compatible output.

The analog to digital converter (ADC) used for the high resolution axis (digitization to ≤ 0.1 FWHM = 1024 channels) must have differential linearity no worse than ± 3 percent. The ADC used for the low resolution axis (digitization to 8, 16, or 64 channels) must have differential linearity no worse than ± 1 percent at 64 channel resolution.

2.3.2 Additional Test Equipment

The following additional test equipment shall be required:

1. Slit mask as shown in Figure 2-1.
2. Lead aperture to mask to the UFOV.
3. Source holder for count rate performance as shown in Figure 2-2.
4. A number of copper absorbers as shown in Figure 2-2.
5. A source holder for the Ga-67 source for the multiple window spatial registration tests.
6. Capillary tubes for the system spatial resolution tests.
7. Acrylic (e.g., Lucite™ or equivalent) scattering material.
8. Dose calibrator.
9. A 100-millimeter-diameter plastic Petri dish.
10. Phantom for dead time measurement with scatter as described in 2.4.10.3.

2.4 TESTS

2.4.1 Intrinsic Spatial Resolution

Intrinsic spatial resolution shall be measured as a performance standard in both the X and Y directions and expressed as full width at half maximum (FWHM) and full

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

width at tenth maximum (FWTM) of the line spread function measured in millimeters.

2.4.1.1. RADIONUCLIDE

The radionuclide employed for this test shall be Tc-99m. Any other radionuclide(s) employed shall be separately reported. A source holder which shields the source from walls, ceilings, and personnel without restricting the gamma flux from source to camera, as shown in Figure 2-3, shall be employed. The analyzer window shall be 20 percent.

2.4.1.2 COUNT RATE

The count rate shall not exceed 20,000 cps through a 20 percent window. Measurements performed at any higher count rate shall be separately reported.

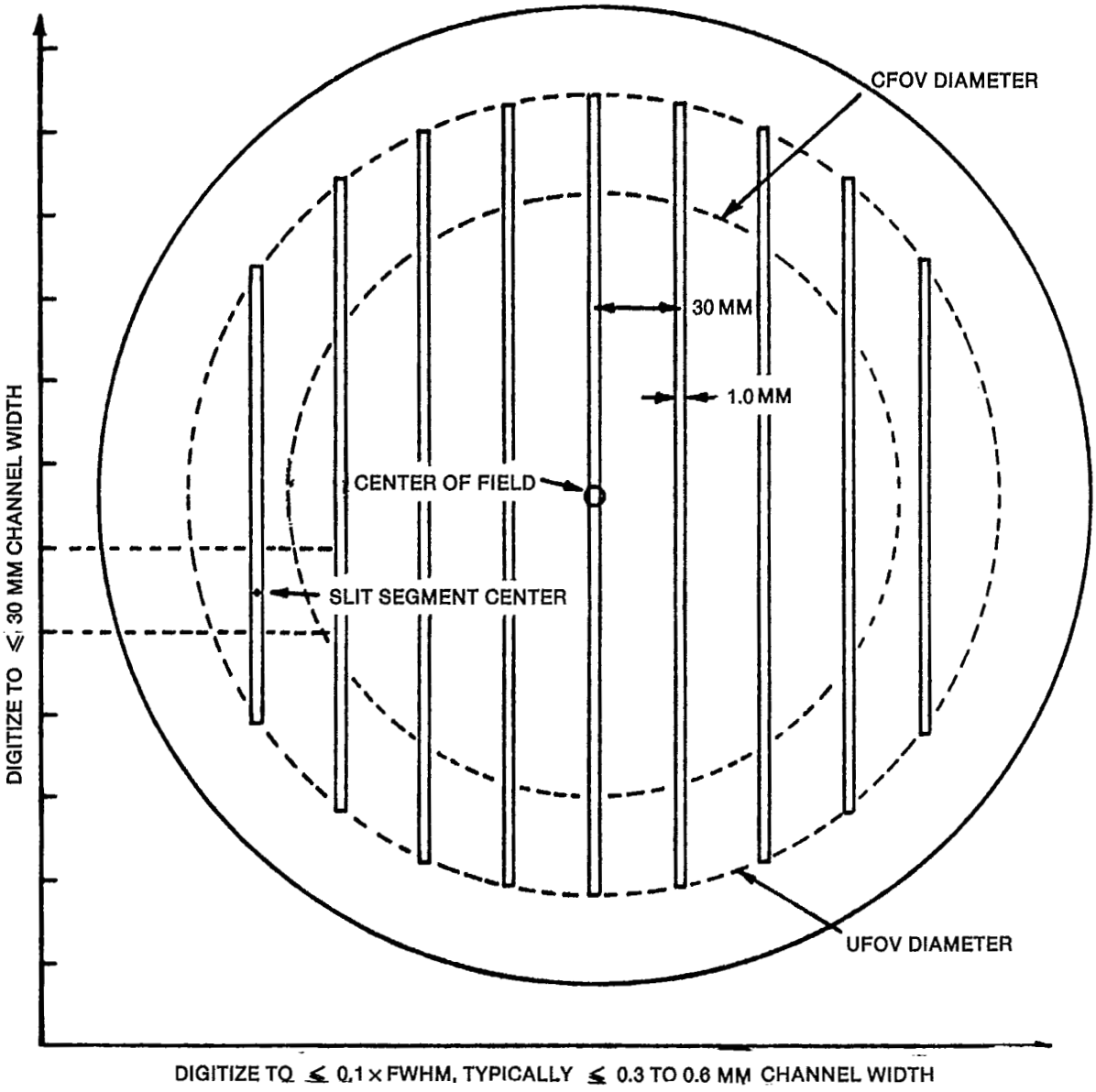


Figure 2-1
EXAMPLE OF RESOLUTION AND LINEARITY MASK FOR A CIRCULAR DETECTOR

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

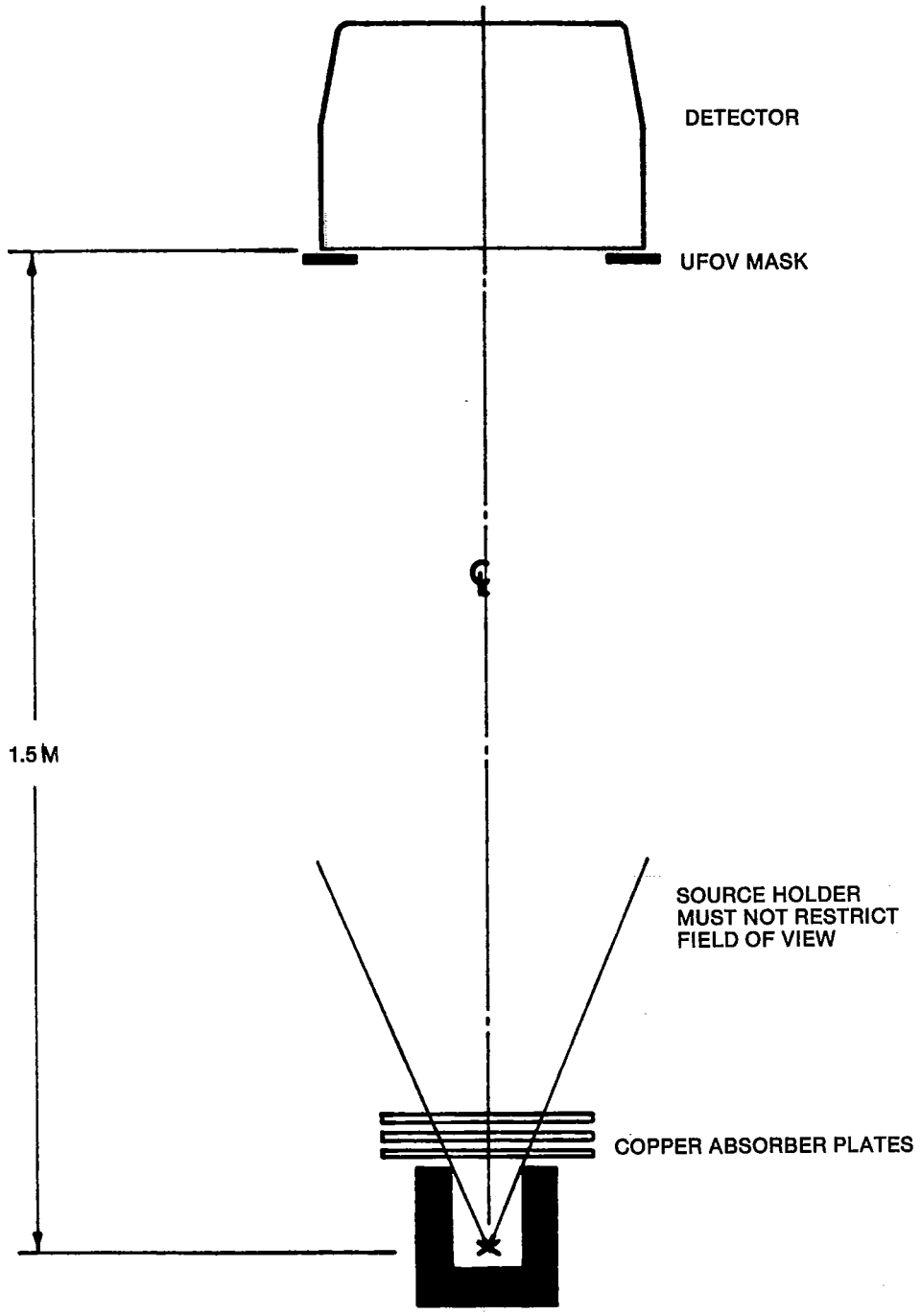


Figure 2-2
GEOMETRY FOR COUNT RATE CURVE
(SINGLE CRYSTAL SCINTILLATION CAMERA)

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

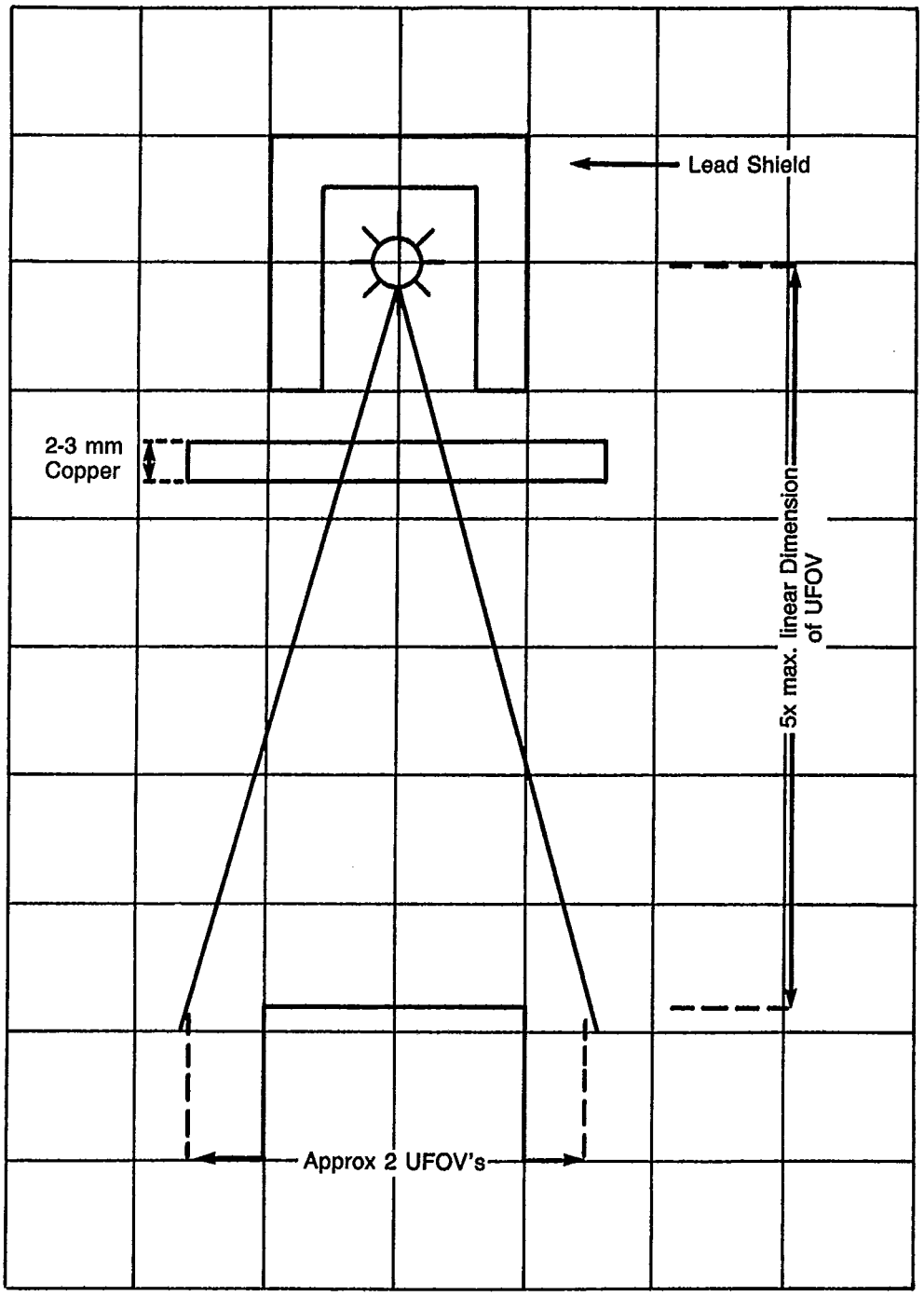


Figure 2-3
COLLIMATED SOURCE GEOMETRY

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

2.4.1.3 TEST PATTERN

The test pattern shall consist of a lead mask in closest possible proximity to the crystal covering the entire field of view with 1-millimeter wide parallel slits on 30 millimeter centers. One of the slits is centered perpendicular to the axis of measurement, and must be aligned rotationally to within ±1 millimeter at the edge of the field. The thickness of the mask shall be 3 millimeters for Tc-99m. Refer to Figure 2-1 which shows an example for circular geometry.

The radionuclide shall be a point source centered at least five times the largest linear dimension of the UFOV above the test pattern.

2.4.1.4 DIGITAL RESOLUTION PERPENDICULAR TO SLITS

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

2.4.1.5 DIGITAL RESOLUTION PARALLEL TO SLITS

The digital resolution parallel to the slits shall correspond to a channel width less than or equal to 30 millimeters.

2.4.1.6 SPREAD FUNCTION MEASUREMENT

At least 1000 counts shall be collected in the peak channel of each line spread function measurement.

2.4.1.7 HALF MAXIMUM AND TENTH MAXIMUM LOCATIONS

The half maximum and tenth maximum locations shall be determined by linear interpolation from the nearest two neighboring values respectively, using the largest value in each line spread function curve as the maximum. Refer to Figure 2-4.

2.4.1.8 MILLIMETERS PER CHANNEL CALIBRATION OF PEAKS

1. The separation of both adjoining peaks shall be averaged in determining the millimeters per channel calibration for each peak.
2. The calculated values are assumed to lie at the center of each 30 × 1 millimeter slit segment.

2.4.1.9 FWHM AND FWTM VALUES

The calculated values of FWHM and FWTM shall not be corrected for background or slit width.

2.4.1.10 FWHM AND FWTM VALUES FOR UFOV

The reported values of FWHM and FWTM for the UFOV shall be the average of all such values for both axes.

2.4.1.11 FWHM AND FWTM VALUES FOR CFOV

The reported values of FWHM and FWTM for the CFOV shall be the average of all such values for both axes lying within the CFOV.

2.4.2 Intrinsic Spatial Linearity

Intrinsic spatial differential linearity and absolute spatial linearity in both X and Y directions shall be measured as performance standards. Differential linearity shall be expressed as millimeters of standard deviation of line spread function peak separations in the CFOV and UFOV using the intrinsic spatial resolution phantom. Absolute linearity shall be measured from the same phantom data and shall be expressed as the maximum amount of spatial displacement measured in the CFOV and UFOV.

2.4.2.1 RADIONUCLIDE

The radionuclide employed for the test shall be Tc-99m. Any other radionuclide(s) employed shall be separately reported. The analyzer window shall be 20 percent. A source holder which shields the source from walls, ceilings, and personnel without restricting the gamma flux from source to camera, as shown in Figure 2-3, shall be employed.

2.4.2.2 COUNT RATE

The count rate shall not exceed 20,000 cps through a 20 percent window. Measurements performed at any higher count rate shall be separately reported.

2.4.2.3 TEST PATTERN

The test pattern shall consist of a lead mask in closest possible proximity to the crystal covering the entire field of view with 1-millimeter wide parallel slits on 30 millimeter centers. One of the slits is centered perpendicular to the axis of measurement, and must be aligned rotationally to within ±1 millimeter at the edge of the field. The thickness of the mask shall be 3 millimeters for Tc-99m. Refer to Figure 2-4 which shows an example for circular geometry. (This test pattern is identical with that of 2.4.1.3).

The radionuclide shall be a point source centered at least 5 times the largest linear dimension of the UFOV above the phantom.

2.4.2.4 DIGITAL RESOLUTION PERPENDICULAR TO SLITS

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

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

2.4.2.5 DIGITAL RESOLUTION PARALLEL TO SLITS

The digital resolution parallel to the slits shall correspond to a channel width less than or equal to 30 millimeters.

2.4.2.6 LINE SPREAD FUNCTION MEASUREMENT

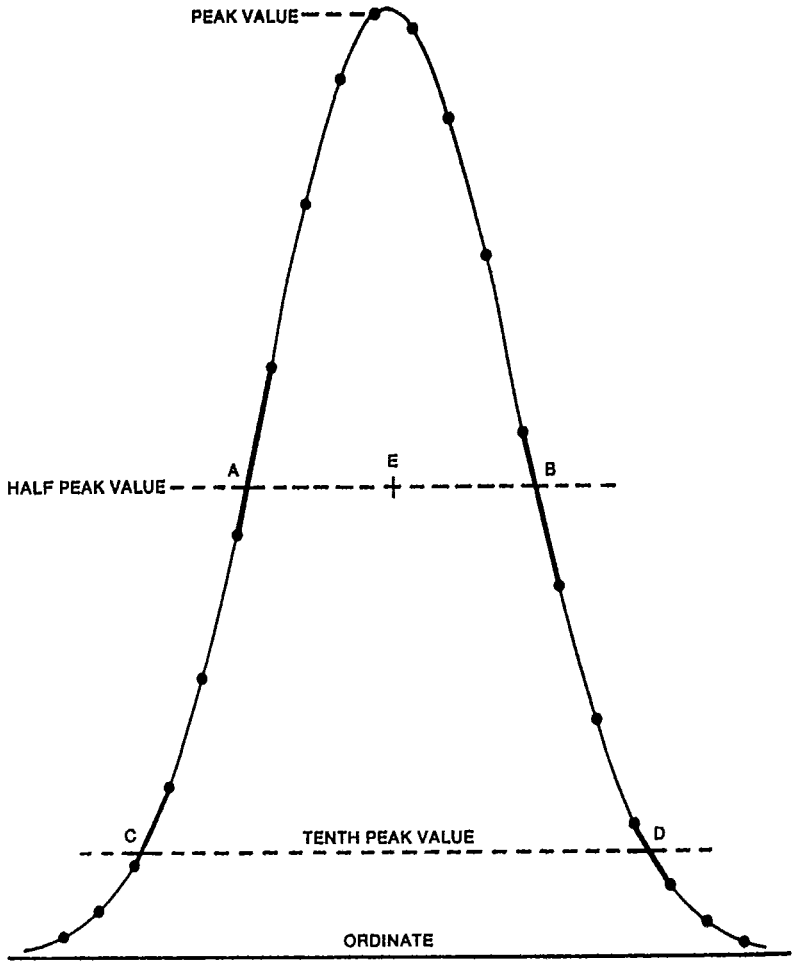
At least 1000 counts shall be collected in the peak channel of each line spread function measurement.

2.4.2.7 LOCATION OF PEAKS

The location of each peak shall be determined from the average of the interpolated half height channel values calculated for each side of the peak.

2.4.2.8 DIFFERENTIAL LINEARITY VALUES

Differential linearity for the CFOV and UFOV shall be reported. Each differential linearity value is the average



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 2-4
LINEAR INTERPOLATION OF HALF MAXIMUM, TENTH MAXIMUM AND CENTER LOCATION FOR SPATIAL RESOLUTION AND ENERGY RESOLUTION

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

of the standard deviations, in millimeters, for both X and Y values together.

Two values shall be reported for differential linearity: one for the average of the X and Y measurements in both the CFOV and UFOV; and each value consisting of the standard deviation in millimeters of adjacent peak separations of all peaks in the specified fields of view.

2.4.2.9 ABSOLUTE LINEARITY

Absolute linearity shall be determined by least-squares fitting equally spaced parallel lines to each of the four data sets separately. Different grids shall be fitted to the CFOV and UFOV data for the X and Y axes separately.

Absolute linearity shall be reported as two values, one value each for the largest of the X or Y displacement in millimeters over the UFOV and CFOV.

Since the data is measured as two sets of one-dimensional data, the maximum displacement for each set shall be the largest deviation from a least-squares best fit to that data set.

The millimeters per channel conversion factors shall be 30 millimeters divided by the average of adjacent peak separations for all peaks in the specified fields of view.

2.4.3 Intrinsic Energy Resolution

As a performance standard, intrinsic energy resolution shall be expressed as the ratio of photopeak full width at half maximum in keV to photopeak energy in keV expressed as a percentage.

2.4.3.1 RADIONUCLIDE

Tc-99m energy resolution shall be reported integrated over the UFOV. Any other radionuclide(s) employed shall be separately reported.

2.4.3.2 SOURCE

The source shall be the same as specified in 2.4.1.1. The detector shall be masked with a 3-millimeter thick lead aperture to establish UFOV.

2.4.3.3 COUNT RATE

The integral count rate shall not exceed 20,000 cps. Measurements performed at any higher count rates shall be separately reported.

2.4.3.4 STORED SPECTRA

All spectra shall be stored to at least 10,000 counts in the peak channel with a digital resolution ≤ 0.05 FWHM.

2.4.3.5 CALIBRATION OF MEASUREMENT INSTRUMENT

A second radionuclide, Co-57, shall be employed in order to calibrate the measurement instrument.

1. Establishment of keV per Channel Calibration Factor—Storing individual spectra for Co-57 and Tc-99m, the difference in channel numbers for the peak centers, determined from the linearly interpolated half-height channels of each photopeak, shall be divided into the difference in photopeak energies (140.5 keV − 122.1 keV = 18.4 keV) to arrive at a keV per channel calibration factor. Refer to Figure 2-4.
2. Intrinsic Energy Resolution—Utilizing the Tc-99m spectrum stored in step 1, above, the FWHM shall be calculated in channels by linear interpolation between the channels surrounding one-half the count value of the peak photopeak channel. This value shall be multiplied by the calibration factor and divided by the photopeak energy (140.5 keV) to arrive at intrinsic energy resolution, expressed in percent.

2.4.4 Intrinsic Flood Field Uniformity

Intrinsic flood field uniformity shall be measured as a performance standard and expressed as "integral uniformity" (a maximum deviation) and "differential uniformity" (a maximum rate of change over a specified distance). Both shall be measured within full field and center field measurement areas (see 2.4.4.4) and expressed as ± percentage values. In addition, as a class standard, point source sensitivity variations shall be expressed as ± percentage variation.

The use of field uniformity correction shall be stated with the results, if so employed.

Refer to Figure 2-5 for a representation of the flood field geometry.

2.4.4.1 RADIONUCLIDE

The radionuclide employed shall be reported for Tc-99m. The same source shall be used as specified in 2.4.1.1. Any other radionuclide(s) employed shall be

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

separately reported. The analyzer window shall be 20 percent.

2.4.4.2 MASKING OF DETECTOR

The detector shall be masked to the UFOV with a lead aperture of at least 3-millimeters thickness. The source shall be placed a minimum of 5 UFOV maximum dimensions above the center of the UFOV.

2.4.4.3 COUNT RATE

The total count rate shall not exceed 20,000 cps through a 20 percent window. Any variations in count rate or window width shall be separately reported.

2.4.4.4 FLOOD FIELD IMAGE

The flood field image shall be stored in a matrix size which produces 6.4 mm ± 20 percent square pixels (approximately 60 pixels over 380 mm).

A minimum of 4000 counts shall be collected in the center pixel of the image.

A flood field image data 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

Pixels outside the full field measurement area shall not be included in the smoothing calculation of pixels within the full field measurement area. The weighting for a pixel outside the full field area in the 9 point filter function shall be zero. The normalization coefficient applied to the filter function for which a weighting factor (or factors) has been zeroed shall be adjusted accordingly.

2.4.4.5 CALCULATION OF FULL FIELD AND CENTER FIELD MEASUREMENT AREAS

The full field and center field measurement areas shall be calculated by first calculating the digital pixel to object space calibration in pixels per centimeter for X and Y separately. This shall be done in accordance with 2.4.2.9 and corrected for the pixel matrix used. The measurement full field area shall be calculated by multiplying the manufacturer's UFOV specification times the pixel calibration factor determined above, keeping X and Y components of the UFOV specification separate.

Field measurement area shall be defined as the centered area excluding 1 pixel on the entire periphery of the UFOV.

The center field measurement area shall be defined as the centered area having dimensions that are 75 percent of the full field area.

2.4.4.6 INTEGRAL UNIFORMITY

For points within the area of interest, the maximum and the minimum values are identified, and their difference calculated. This result is divided by the sum of the values at these two points, multiplied by 100 percent, and expressed as a ± percentage integral uniformity. The formula for integral uniformity shall be as follows:

$$\text{Integral Uniformity} = \pm\ 100\% \left(\frac{\text{Max} - \text{Min}}{\text{Max} + \text{Min}}\right)$$

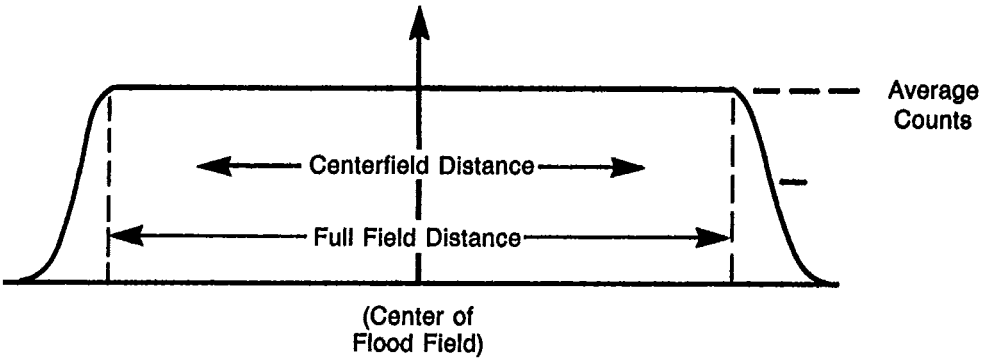


Figure 2-5
FLOOD FIELD GEOMETRY WITH CRYSTAL AREA MASKED TO UFOV

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

2.4.4.7 DIFFERENTIAL UNIFORMITY

Differential uniformity is the measurement of the worst case rate of change of the flood field over a 5-pixel distance.

The flood is treated as a number of rows and columns (slices). Each slice is processed by starting at one end, examining a set of 5 pixels including the start pixel and recording the maximum difference. The start pixel is moved forward one pixel and the next set of 5 pixels is examined,and so on. For the whole set of slices, the largest deviation is found. This largest deviation is divided by the sum of the values for the two points representing the largest deviation, multiplied by 100 percent and expressed as a ± percentage differential uniformity. These calculations shall be performed for the Full Field and Center Field areas.

$$\text{Differential uniformity} = \pm\ 100\ \% \left(\frac{\text{High} - \text{Low}}{\text{High} + \text{Low}}\right)$$

High and low are obtained from the largest five pixel deviations. High is the maximum pixel value and low is the minimum count value.

2.4.5 Point Source Sensitivity Variation

As a class standard, point source sensitivity variation shall be reported for a collimated point source of Tc-99m at each point of a matrix centered in the UFOV with the space between points on each axis to be 30 millimeters. There shall typically be approximately 50 points for a 25.4 centimeter diameter camera and 125 points for a 38.1 centimeter diameter camera.

2.4.5.1 SOURCE

The Tc-99m source shall be collimated through a hole 3 millimeters in diameter by a minimum of 6 millimeters in length.

2.4.5.2 ANALYZER WINDOW

The analyzer window shall be 20 percent. The count rate shall not exceed 10,000 cps.

2.4.5.3 TIME INTERVAL OF COUNTS

The number of counts registered during a fixed time interval shall be recorded; the time interval shall be chosen so that the counts shall exceed 10,000 counts for any point in the matrix.

2.4.5.4 DECAY OF RADIONUCLIDE

The measurement shall be corrected for the decay of the radionuclide.

2.4.5.5 SENSITIVITY VARIATION

For all measured points within the UFOV, the maximum and minimum values are identified, and their difference calculated. This "span" is divided by the sum of the values at these two points, multiplied by 100 percent, and expressed as a ± percentage sensitivity variation. The formula for sensitivity variation is as follows:

$$\text{Sensitivity Variation} = \pm 100\% \left(\frac{\text{Max} - \text{Min}}{\text{Max} + \text{Min}}\right)$$

2.4.6 Intrinsic Count Rate Performance

Five parameters shall be measured and reported: observed count rate for a 20 percent count loss, and maximum count rate as performance standards; and as class standards, typical input versus observed count rate curve, intrinsic spatial resolution at 75,000 cps (observed) and intrinsic flood field uniformity at 75,000 cps (observed).

2.4.6.1 RADIONUCLIDE

The results shall be reported for Tc-99m. Any other radionuclide(s) employed shall be separately reported. The source holder of Figure 2-3 shall be employed. The analyzer window shall be 20 percent. Peaking shall be performed at a low count rate and shall not be manually readjusted during the test.

2.4.6.2 TWENTY PERCENT COUNT LOSS RATE

The 20 percent count loss rate shall be calculated on the assumption that the camera behaves as a purely paralyzable system over the range from $R_{-20\%}/2$ (one-half of the 20 percent count loss count rate) to $R_{-20\%}$ (the 20 percent count loss count rate) and thus shall be calculated in accordance with the following formula:

$$R_{obs} = Re^{-RT}$$

1. Dead Time—The dead time T shall be determined according to a modified two-source measurement and calculated according to the formula:

$$T = \left(\frac{2R_{12}}{(R_1 + R_2)^2}\right) \ln \left(\frac{R_1 + R_2}{(R_{12})}\right)$$

2. Observed Count Rate—The observed count rate for 20 percent loss ($R_{-20\%}$) shall then be calculated from:

$$R_{-20\%} = \frac{1}{T} \ln \left(\frac{10}{8}\right)(0.8) = \left(\frac{0.2231}{T}\right)(.8) = \frac{0.1785}{T}$$

3. Acquisition of Data—Select sources R_1 and R_2 to be within ±10 percent of each other. The count rate for both sources present, R_{12}, must approximate the

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

anticipated 20 percent loss count rate, within ±20 percent. The data will be acquired by masking the camera crystal to the UFOV and suspending one source near the crystal axis at a distance greater than 1 meter as required to obtain the desired count rate. Record the count rate (R_1). Add a second source R_2 in such a fashion that neither source obscures the other's view of the crystal. Record R_{12}. Remove the first source and record R_2. For Tc-99m and other short-lived sources, repeat the procedure backwards and average the count rate values. Background is assumed to be negligible in comparison to the strength of the sources.

4. Reported Value—Report the observed count rate for 20 percent loss.

2.4.6.3 MAXIMUM COUNT RATE

The maximum count rate shall be determined by setting the window to 20 percent with the camera crystal masked to the UFOV. The camera shall be slowly approached with about a 2mCi Tc-99m source and the maximum observed count rate shall be recorded. Care must be taken to minimize scatter.

2.4.6.4. MEASUREMENT OF TYPICAL INPUT VERSUS OBSERVED COUNT RATE CURVE

As a class standard, the data for a typical input versus observed count rate curve shall be measured as follows (Refer to Figure 2-2 when following these instructions):

1. Copper Absorber Plates—A number of equal thickness copper absorber plates, individually calibrated for attenuation of Tc-99m gammas (approximately 2.5 millimeters thick) are placed between the source, in close proximity to the source, and the detector masked to the UFOV.
2. Source—The source shall be a Tc-99m point source, placed 1.5 meters in front of the center of the detector.
3. Shielding of Source—The source shall be shielded with no less than 6 millimeters of lead on the back and sides to prevent excessive background radiation and scatter.
4. Absorber Plates—The number of absorber plates to produce a background corrected count rate no greater than 2500 cps shall be determined. From this count rate, knowing the calibration of each absorber and the decay rate of the source, any input count rate can be obtained by removal of a calculated number of absorber plates.
5. Foldover in Observed Count Rate Curve—At least 8 data points shall be measured between zero input count rate and that input count rate required to produce foldover in the observed count rate curve.
6. Typical Count Rate—The input rate versus observed rate points shall be graphed, curve fitted, and labeled as typical count rate.

2.4.6.5. INTRINSIC SPATIAL RESOLUTION MEASUREMENTS

The intrinsic spatial resolution measurements listed in 2.4.1 shall be performed for the UFOV only, at an observed count rate of 75,000 cps through a 20 percent window and reported as class standard values.

2.4.6.6. INTRINSIC FLOOD FIELD UNIFORMITY MEASUREMENTS

The intrinsic flood field uniformity measurements listed in 2.4.4 shall be performed at an observed count rate of 75,000 cps through a 20 percent window and reported as class standard values.

2.4.7 Multiple Window Spatial Registration

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

2.4.7.1 RADIONUCLIDE

The results are to be reported for Ga-67. If the camera has two windows, the peaks at 93 keV and 296 keV shall be employed. For three windows, the peak at 184 keV shall be additionally employed.

2.4.7.2 TOTAL COUNT RATE

The count rates shall not exceed 10,000 cps through each window. Each window shall be set to 20 percent.

2.4.7.3 COMPUTATION OF Ga-67 SOURCE DISPLACEMENT

A Ga-67 source, collimated through a hole 5 millimeters in diameter by a minimum of 25 millimeters in length, shall be placed at two points on each (X and Y) axis, acquired through the 2(3) windows, and the displacement in millimeters computed.

2.4.7.4 X-AXIS DISPLACEMENT MEASUREMENT

1. Digital Resolution—For the X-axis displacement measurement, the digital resolution shall be ≤0.1 FWHM (see 2.4.1.4) in the X-axis. Y-axis resolution is irrelevant.
2. Peak Channel Count—The collimated source shall be placed on the +X axis, (on the CFOV edge). Through each window, independently, at least 10,000 counts in the peak channel shall be acquired.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

3. Peak Center(s) Displacement—The center of the peak for each window shall be determined as the average of the half maximum channels as described in 2.4.1.7. The displacement(s) (one or two) shall be the difference in the 296 keV peak (and 184 keV peak) center(s) from the center of the 93 keV peak.
4. Source—The source shall be moved to a point on the −X-axis, on the edge of the CFOV. The measurement and calculation shall be repeated and knowing the distance between the two source locations, the two (or four) X displacement values for each point spread function shall be converted into millimeters.
5. Maximum X Registration Error—The largest of these 2 (or 4) X displacement values in millimeters shall be recorded as the maximum X registration error.

2.4.7.5 Y-Axis Displacement

The Y axis displacement values are measured via the procedure in 2.4.7.4, substituting Y axis and X axis, and the maximum Y registration error in millimeters is recorded.

2.4.7.6 Reporting of Displacement Factor

The larger of the X or Y displacements shall be reported.

2.4.8 System Spatial Resolution With and Without Scatter

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

2.4.8.1 Radionuclide

The radionuclide to be employed for this measurement shall be Tc-99m. Any other radionuclide(s) employed for higher energy collimators shall be separately reported.

2.4.8.2 Count Rate

The count rate shall not exceed 20,000 cps through a 20 percent window. Measurements performed at any higher count rate shall be separately reported. The analyzer shall be peaked with the sources in air and shall not be manually readjusted during the test.

2.4.8.3 Source

1. Composition of Sources—The sources shall consist of two capillary tubes, with an inside diameter ≤ 1.0 millimeter, and a length greater than 30 millimeters.
2. Location of Sources—The sources shall be located at a distance of 100 millimeters from the face of the collimator. If resolution at other depths is reported, the depths shall be in 50 millimeter increments including 100 millimeters.
3. Measuring System Spatial Resolution Without Scatter—For measuring system spatial resolution without scatter, no scattering medium shall be introduced between the capillary tube(s) and the collimator or behind the capillary tube(s).
4. Measuring System Spatial Resolution With Scatter—For measuring system spatial resolution with scatter, 100 millimeters of acrylic (e.g. Lucite™ or equivalent) shall be interposed between the capillary tube(s) and the collimator, and 50 millimeters of acrylic, shall be placed behind the capillary tube(s). The acrylic, (e.g. Lucite™ or equivalent) may be assembled from thinner pieces but must cover the entire UFOV.

2.4.8.4 Measurement of FWHM and FWTM Axes

1. Method—The measurement for each axis of FWHM and FWTM shall be performed with a single capillary tube lying along the diameter corresponding to the axis of measurement and aligned to the diameter within ± 1 millimeter.
2. Calibration Measurement—A second measurement for each axis shall be performed with the second capillary tube placed 50 millimeters away from and parallel with the first tube. This measurement shall be used for calibration purposes only.
3. Digital Resolution—The digital resolution perpendicular to the tube(s) shall be ≤ 0.1 FWHM. The digital resolution parallel to the tube(s) shall be no greater than 30 millimeters.
4. Peak Point Counts—At least 10,000 counts shall be collected in the peak point of each line spread function.
5. Calculation and Calibration Measurements of FWHM and FWTM—Per the procedure in 2.4.1.7, the FWHM and FWTM shall be calculated in channel numbers from the measurement of step 1, above, and calibrated by the measurement of step 2, above.
6. Reported FWHM and FWTM Values—The reported FWHM and FWTM values shall be those values measured within the CFOV and independently averaged for the X and Y axes. The use of scattering material per step 4 of 2.4.8.3 shall be clearly indicated.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

2.4.8.5. CALCULATION OF SYSTEM SPATIAL RESOLUTION BASED UPON AN INTRINSIC SPATIAL RESOLUTION MEASUREMENT

System spatial resolution shall be reported as a calculated value based on an intrinsic spatial resolution measurement.

1. Collimator Resolution—From a system spatial resolution measurement of 2.4.8.4 and an intrinsic spatial resolution over the CFOV of 2.4.1.11, collimator resolution shall be calculated from:

$$R_s = \left(R_c^2 + (R_i/M)^2\right)^{1/2}$$

Where: R_s = System spatial resolution (FWHM or FWTM)
R_c = Collimator resolution (FWHM or FWTM)
R_i = Intrinsic resolution (FWHM or FWTM)
M = Image magnification factor (image size/object size)

For parallel hole collimators M equals 1. For pinhole collimators, M is the ratio of aperature to detector distance divided by object to aperature distance. For diverging collimators ($M < 1$) and converging collimators ($M > 1$), M is the ratio of image size to object size for the object at a given depth (100 millimeters nominal).

2.4.9 System Sensitivity

As a class standard, the system sensitivity (camera and collimator) shall be measured for each collimator and reported in counts/(minute.uCi) of the measured radionuclide for 20 percent windows.

2.4.9.1. RADIONUCLIDES

The radionuclides employed for these measurements shall be those for which the collimator is designed. The collimator energy and radionuclide used for energy shall be reported.

2.4.9.2 COUNT RATES

The count rate shall not exceed 20,000 cps through a 20 percent window. Measurement performed at any higher count rate shall be separately reported.

2.4.9.3. CALIBRATION OF SOURCE INTENSITY

The source intensity shall be accurately measured with a calibrated dose calibrator. The source shall be dispersed from the syringe into a shallow solution (approximately 3 millimeters in depth) in a 100 millimeter diameter sealed plastic dish, placed near the center of the collimator field of view 100 millimeters from the face of the collimator. The "empty" syringe shall be re-read in the dose calibrator and this reading sub-tracted from the original reading to obtain the amount of activity in the dish.

Calibration methods shall be based on those set forth in the NRC Regulatory Guide 10.8 or alternatively, NBS traceable calibrated sources shall be used as references, with appropriate half-life correction.

Counts/(minute.uCi) shall be reported. The identification of the collimator and camera shall be reported.

In this context, "counts" shall be defined as interactions in the crystal that fall within the analyzer window; therefore, field uniformity correction devices which alter the number of counts must be disabled.

Having established the absolute sensitivity of one collimator and camera combination, for other collimators, it is permissible to perform relative sensitivity measurements and calibrate those measurements with respect to the original absolute measurement. (This sentence approved as Authorized Engineering Information.)

2.4.10 System Count Rate Performance with Scatter

As a class standard, the observed count rate for a 20 percent count loss shall be reported. If circuitry is used to correct the output count rate for deadtime losses, then such circuitry must be disabled in reporting this measurement. If such circuitry cannot be disabled, then this measurement must be reported as "not applicable."

2.4.10.1 RADIONUCLIDE

The radionuclide to be employed for this measurement shall be Tc-99m. Any other radionuclide(s) employed shall be reported separately. The analyzer window shall be 20 percent and centered on the photo-peak. The phantom to be used is specified in 2.4.10.3.

2.4.10.2 COLLIMATION

The low energy parallel hole collimator of highest sensitivity shall be employed. Any other collimators which are used shall be reported separately.

2.4.10.3 PHANTOM AND PROCEDURE

2.4.10.3.1 Phantom—The phantom shall consist of two Tc-99m sources containing activity within 10 percent of each other's dose, in capped tubes which fit within 1.6 cm diameter by 120 mm long cavities. The tubular cavities shall be positioned 50 mm

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

50 mm apart in a solid acrylic (e.g. Lucite™ or equivalent) phantom measuring 150 mm × 200 mm × 200 mm. Refer to Figure 2-6.

2.4.10.3.2 Procedure—Record the count rate (R_1). Add R_2 in such a fashion that neither source obscures the other's view of the crystal. Record R_{12}. The count rate for both sources present, R_{12}, must approximate the anticipated 20 percent loss count rate, within ±20 percent. Remove the first source and record R_2. For Tc-99m and other short-lived sources, repeat the procedure backwards and average the count rate values. In order to achieve best results, background must be negligible in comparison to the source.

2.4.10.4 20 Percent Count Loss Rate with Scatter

As a class standard, the observed count rate for 20 percent loss shall be calculated under scatter conditions. See A.1.2.10. The behavior of paralyzable systems are approximated by the Poisson statistical distribution in accordance with the formula:

$R_{obs} = Re^{-RT}$

Where R_{obs} = observed count rate
R = true input count rate
T = dead time

1. Calculation of Dead Time—The paralyzable dead time shall be calculated as:

$$T\ (\text{usec}) = \left(\frac{2R_{12}}{(R_1 + R_2)^2}\right) \ln\left(\frac{R_1 + R_2}{(R_{12})}\right)$$

2. Observed Count Rate—The observed count rate for 20 percent loss (−20%) shall then be calculated as:

$$R_{-20\%} = .8\left(\frac{1}{T}\right) \ln\left(\frac{10}{8}\right) = \left(\frac{.1785}{T}\right)$$

3. Acquisition of Data—The data will be acquired with the tubular sources of activity parallel to the collimator and with the 20 cm × 20 cm face of the phantom closest to the sources against the surface of the collimator. The tubes shall be vertical (to lessen the chance of radioactive spills), with the midpoint between them at the center of the UFOV. A constant elapsed time between each of the source measurements described below shall be maintained to counteract the effects of radioactive decay. Assure that background is negligible compared to the source used.
   a. Count Rate Source, R_1—Place source 1 in the phantom and record the counts acquired in 100 seconds and divide by 100 seconds.
   b. Combined Count Rate, R_{12}—Add source 2 to the phantom and record the combined counts acquired in 100 seconds and divide by 100 seconds.
   c. Count Rate Source Alone, R_2—Remove source 1 and record the counts acquired in 100 seconds and divide by 100 seconds.
   d. Repeat the Measurements—Repeat the above set of measurements in reverse order and average the respective results.
4. Reported Values—Report the observed count rate for 20 percent loss.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

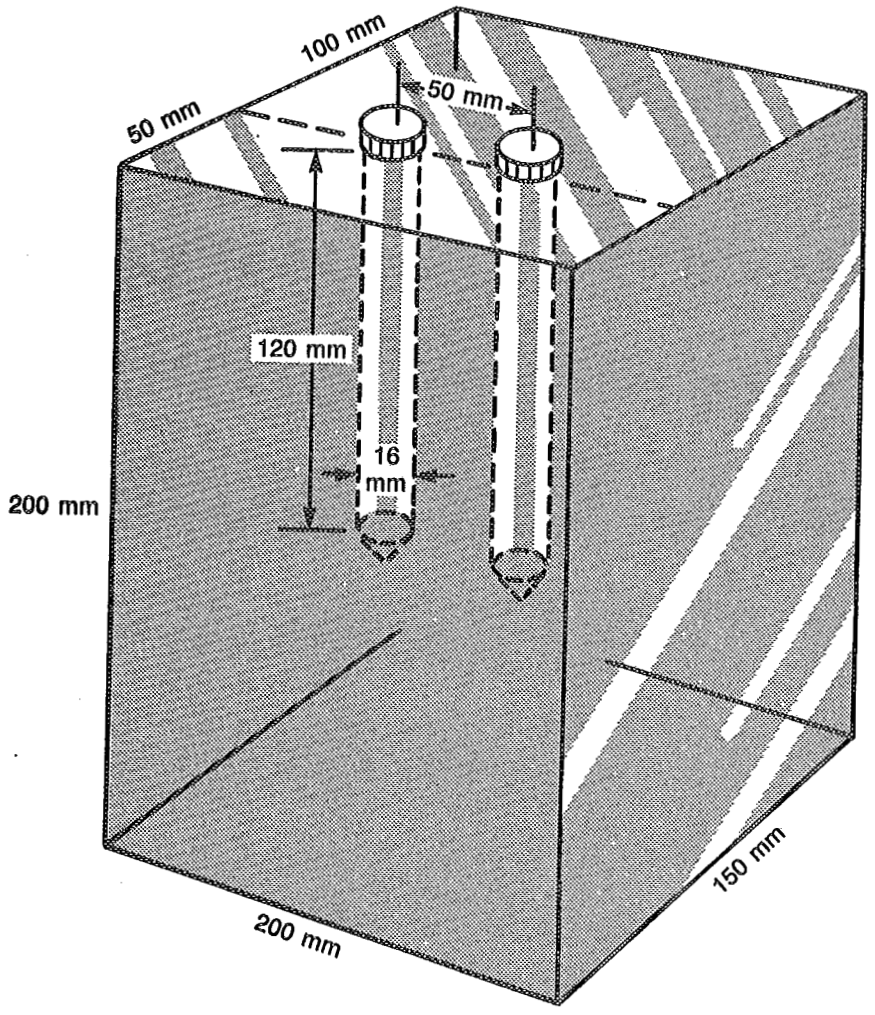


Figure 2-6
PHANTOM FOR MEASUREMENT OF SYSTEM COUNT RATE WITH SCATTER

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Section 3

MULTIPLE CRYSTAL SCINTILLATION CAMERA TEST METHODS

3.1 DEFINITIONS

The definitions contained in Section 3 apply only to multiple crystal scintillation cameras. Refer to Section 1 for general definitions which apply to both single and multiple crystal scintillation cameras.

The useful field of view (UFOV) is that area defined by a dimensioned figure supplied by the manufacturer.

3.2 GENERAL

3.2.1 Reported Values

In stating specifications, all reported values shall be labeled as "worst case", "better than", "not to exceed", and UFOV, and the collimator shall be specified, except where otherwise defined in this document. In the case of Class Standard values, a typical value shall be reported.

3.2.2 Additional Tests

Any additional tests, at variance with any test parameters, shall be separately reported and the variance shall be clearly indicated.

3.2.3 Correction Devices

If field uniformity, or energy corrections are employed, all measurements shall be consistently performed with these corrections on or off and the results so indicated.

3.2.4 Traceability

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.

3.3 TEST EQUIPMENT

3.3.1 Test Equipment Performance

All tests shall be performed utilizing the data processing capabilities of the multiple crystal scintillation camera. Measurements of field uniformity and energy resolution, or both energy resolution and field uniformity, shall be specified as intrinsic or system corrected.

3.3.2 Minimum Test Equipment Requirements

The following test equipment shall be required:

1. Slit mask as shown in Figure 3-1.
2. Tc-99m point source.
3. Source holder for count rate performance as shown in Figure 3-2.
4. A number of copper absorber plates.
5. Tc-99m capillary tube sources (two each) for the system spatial resolution tests.
6. Acrylic (e.g. Lucite™ or equivalent) scattering material, 100 and 50 millimeters thick (same area as UFOV).
7. Dose calibrator traceable to an NBS source.
8. A 100 millimeter-diameter Petri dish.
9. Phantom for dead time measurement with scatter.
10. Scatter test source holders as shown in Figure 2-2.

3.4 TESTS

3.4.1 Intrinsic Spatial Resolution

The concept of intrinsic spatial resolution as defined for single crystal cameras is not analogous, nor directly applicable to that of multicrystal cameras. Overall system spatial resolution is described in 3.4.9.

3.4.2 Intrinsic Spatial Linearity

The concept of intrinsic spatial linearity as defined for single crystal cameras is not analogous, nor directly applicable to that of multicrystal cameras. Overall system linearity is described in 3.4.6.

3.4.3 Instrinsic Energy Resolution

Intrinsic energy resolution as a performance standard shall be expressed as the ratio of photopeak full width at half maximum in keV to photopeak energy in keV expressed as a percentage.

3.4.3.1 RADIONUCLIDE

Tc-99m energy resolution shall be reported integrated over the UFOV. Any other radionuclide(s) employed shall be separately reported.

3.4.3.2 SOURCE

The source shall be a point source placed directly above the center of the UFOV at a minimum distance equivalent to 5 times the long axis of the UFOV. No collimator shall be used. A source holder which shields the source from walls, ceilings, and personnel without restricting the gamma flux from source to camera, as shown in Figure 2-2, shall be employed.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

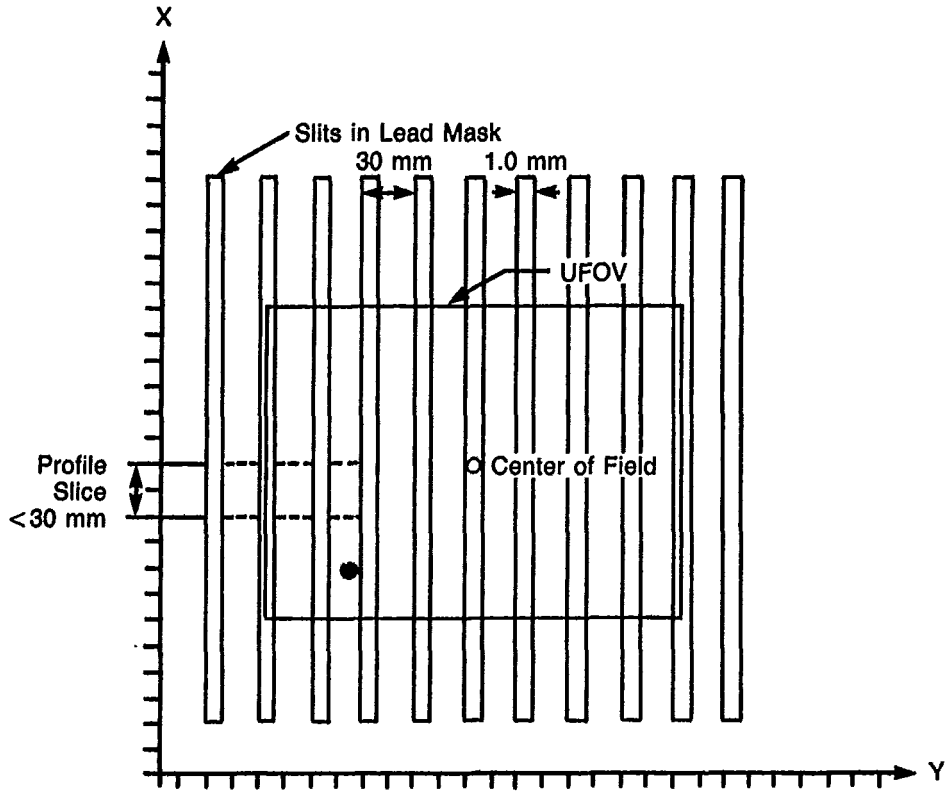


Figure 3-1
LINEARITY PHANTOM

3.4.3.3 COUNT RATE

The integral count rate shall not exceed 20,000 cps. Measurements performed at any higher count rates shall be separately reported.

3.4.3.4 STORED SPECTRA

All spectra shall be stored to at least 10,000 counts in the peak channel with a digitization resolution ≤0.05 FWHM.

3.4.3.5 CALIBRATION OF ENERGY SPECTRUM

A second radionuclide, Co-57, shall be employed to calibrate the measurement instrument.

1. Establishment of keV Per Channel Calibration Factor—In storing individual spectra for Co-57 and Tc-99m, the difference in frame numbers for the peak centers, determined from the linearly interpolated half height channels of each photopeak, shall be divided into the difference in photopeak energies (140.5keV−121.−1keV= 18.4keV) to arrive at a keV per channel calibration factor. Refer to Figure 2-4.
2. Intrinsic Energy Resolution—Utilizing the Tc-99m spectrum stored in step 1 above, the FWHM shall be calculated in channels by linear interpolation between the channels surrounding one-half the count value of the peak photopeak channel. This value shall be multiplied by the calibration factor and divided by the photopeak energy (140.5 keV) to arrive at the intrinsic energy resolution, expressed in percent.

3.4.4 System Flood Field Uniformity

System flood field uniformity shall be measured as a performance standard and expressed as "integral uniformity" (maximum deviation) and "differential uniformity"

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

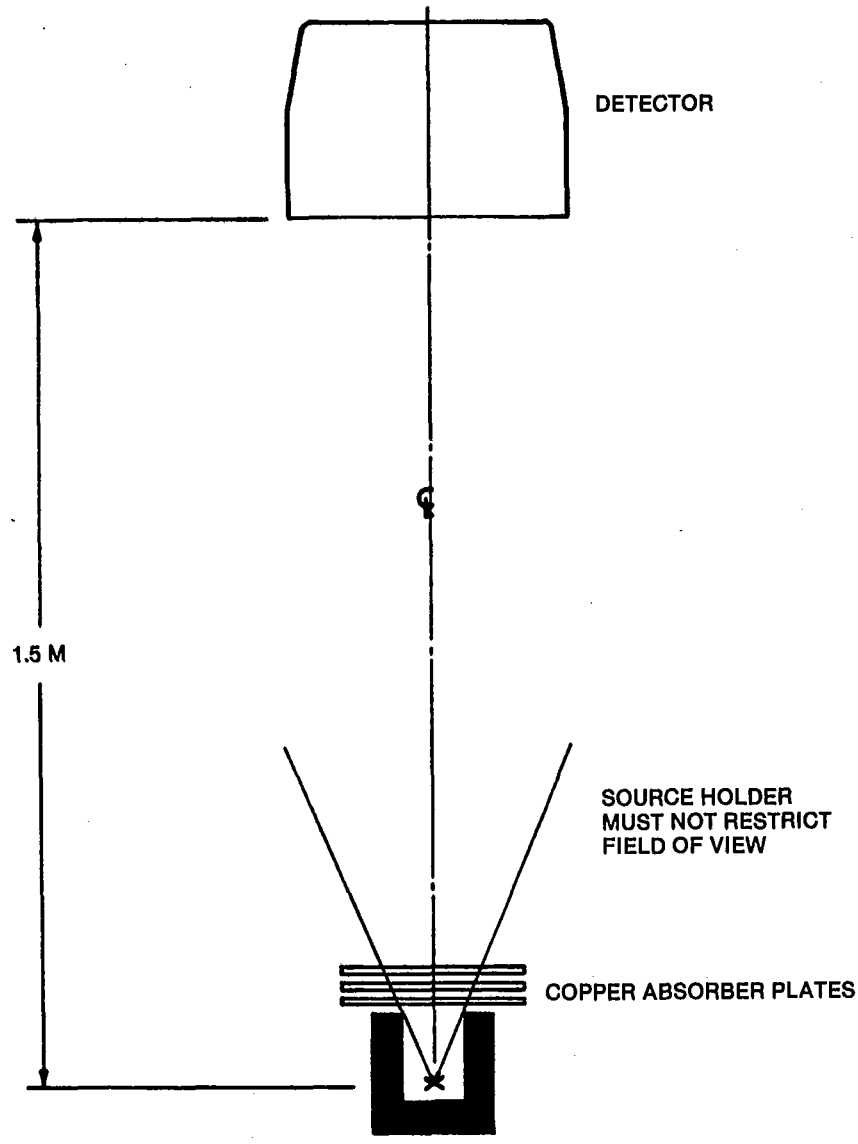


Figure 3-2
GEOMETRY FOR COUNT RATE CURVE
(MULTIPLE CRYSTAL SCINTILLATION CAMERA)

(maximum deviation) and "differential uniformity" (maximum rate of change over a specified distance, roughly slope). Both shall be measured for the UFOV (see 3.4.4.4) and expressed as ± percentage values. In addition, as a class standard, point source sensitivity variations shall be expressed as ± percentage variation.

The use of field uniformity correction shall be stated with the results, if so employed.

3.4.4.1 RADIONUCLIDE

The radionuclide employed shall be Tc-99m in the form of a flood source placed in contact with the collimator. Any other radionuclide(s) employed shall be separately reported. The analyzer window shall be 20 percent.

3.4.4.2 COLLIMATOR

The collimator shall be a parallel hole collimator of maximum sensitivity.

3.4.4.3 COUNT RATE

The total count rate shall not exceed 30,000 cps through a 20 percent window. Any variations in count rate or window width shall be separately reported.

3.4.4.4 FLOOD FIELD IMAGE

The flood field image shall be stored in a matrix having as many points as there are detector elements.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

3.4.4.5 INTEGRAL UNIFORMITY

For points within the area of interest (UFOV), the maximum and the minimum values shall be identified, and their difference calculated. This "span" is divided by the sum at these two points, multipied by 100 percent, and expressed as a ± percentage integral uniformity. The formula for integral uniformity shall be as follows:

$$\text{Integral Uniformity} = \pm 100\% \left(\frac{\text{Max} - \text{Min}}{\text{Max} + \text{Min}}\right)$$

3.4.4.6 DIFFERENTIAL UNIFORMITY

Differential uniformity is the measurement of the worst case rate of change of the flood field over a distance. The flood is treated as a number of rows and columns (slices).

Each slice is processed by starting at one end, examining a set of 5 pixels including the start pixel and recording the maximum difference. The start pixel is moved forward one pixel and the next set of pixels is examined, etc. For the whole set of slices the largest deviation is found. This largest deviation is divided by the sum of the values for the two points representing the largest deviation, multiplied by 100 percent, and expressed as a ± percentage diffential uniformity in the UFOV.

$$\text{Differential Uniformity} = \pm 100\% \left(\frac{\text{High} - \text{Low}}{\text{High} + \text{Low}}\right)$$

3.4.5 Point Source Sensitivity Variation

As a class standard, point source sensitivity variation shall be reported for a collimated point source of Tc-99m centered at each detector element of the UFOV with the space between points on each axis to be 10 millimeters. The use of field uniformity correction shall be stated with the results, if so employed.

3.4.5.1 SOURCE

The Tc-99m source shall be collimated through a hole 3 millimeters in diameter by a minimum of 6 millimeters in length. The source shall be diluted to be no less than 10 millimeters in depth in the source holder.

3.4.5.2 ANALYZER WINDOW

The analyzer window shall be 20 percent. The count rate shall not exceed 10,000 cps.

3.4.5.3 TIME INTERVAL OF COUNTS

The number of counts registered during a fixed time interval shall be recorded; the time interval shall be chosen so that the counts shall exceed 100,000 counts for any point in the matrix.

3.4.5.4 DECAY OF RADIONUCLIDE

The measurement shall be corrected for the decay of the radionuclide.

3.4.5.5 SENSITIVITY VARIATION

For all measured points within the UFOV, the maximum and minimum values are identified, and their difference calculated. This "span" is divided by the sum of the values at these two points, multiplied by 100%, and expressed as a ± percentage sensitivity variation. The formula for sensitivity variation is as follows:

$$\text{Sensitivity Variation} = \pm 100\% \left(\frac{\text{Max} - \text{Min}}{\text{Max} + \text{Min}}\right)$$

3.4.6 System Spatial Linearity

System spatial differential linearity and absolute spatial linearity in both X and Y directions shall be measured as performance standards. Differential linearity shall be expressed as millimeters of standard deviation of line spread function peak separations in the UFOV using the spatial linearity test pattern, (described in 3.4.6.3). Absolute linearity shall be measured from the same data and shall be expressed as the maximum amount of spatial displacement measured in the UFOV.

3.4.6.1 RADIONUCLIDE

The radionuclide to be employed for this measurement shall be Tc-99m. Any other radionuclides employed shall be separately reported. The analyzer window shall be 20 percent. The radionuclide shall be in the form of a flood source placed in contact with test pattern.

3.4.6.2 COUNT RATE

The count rate shall not exceed 10,000 cps through a 20 percent window. Measurements performed at any higher count rate shall be separately reported.

3.4.6.3 TEST PATTERN

The test pattern shall consist of a lead mask covering the UFOV in closest possible proximity to the collimator covering the entire field of view with 1-millimeter wide parallel slits on 30 millimeter centers and must be aligned rotationally to within ±1 millimeter at the edge of the field. The thickness of the mask shall be 3 millimeters for Tc-99m. Refer to Figure 3-1.

3.4.6.4 DIGITAL RESOLUTION PERPENDICULAR TO SLITS

The spatial digital resolution employed shall be that obtained in a static multiposition study utilizing the scanning capabilities of the imaging device.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

3.4.6.5 DIGITAL RESOLUTION PARALLEL TO SLITS

The digital resolution parallel to the slits shall correspond to a profile width less than or equal to 30 millimeters.

3.4.6.6 LINE SPREAD FUNCTION MEASUREMENT

At least 1000 counts shall be collected in the peak channel of each line spread function measurement.

3.4.6.7 LOCATION OF PEAKS

The location of each peak shall be determined from the average of the interpolated half height channel values calculated for each side of the peak.

3.4.6.8 DIFFERENTIAL LINEARITY VALUES

Differential linearity for the UFOV shall be reported. Each differential linearity value is the average of the standard deviations, in millimeters, for both X and Y values together.

Two values shall be reported for differential linearity: one for the average of the X and Y measurements in the UFOV; and each value consisting of the standard deviation in millimeters of adjacent peak separations of all peaks in the UFOV.

The millimeters per channel conversion factors shall be 30 millimeters divided by the average of adjacent peak separations for all peaks in the specified fields of view.

3.4.6.9 ABSOLUTE LINEARITY

Absolute linearity shall be determined by least squares fitting equally spaced parallel lines to each of the two data sets separately. Different grids shall be fitted to the UFOV data for each axis separately.

Absolute linearity shall be reported as two values. One value each for the largest of the X or Y displacement in millimeters over the UFOV.

Since the data are measured as two sets of one-dimensional data, the maximum displacement for each set shall be the largest deviation from a least-squares best fit to that data set. The millimeters per channel conversion factors shall be 30 millimeters divided by the average of adjacent peak separations for all peaks in the UFOV.

3.4.7 Intrinsic Count Rate Performance

Five parameters shall be measured and reported: input count rate for a 20 percent count loss; maximum count rate as performance standards; and as class standards, typical input versus observed count rate curve; system spatial resolution as 75,000 cps (observed); and system flood field uniformity at 75,000 cps (observed).

3.4.7.1 RADIONUCLIDE

The radionuclide employed shall be Tc-99m. Any other radionuclide(s) employed shall be separately reported. The source holder for Figure 2-1 shall be employed. The analyzer window shall be 20 percent.

3.4.7.2 TWENTY PERCENT COUNT LOSS RATE

The 20 percent count loss rate shall be calculated on the assumption that the camera behaves as a purely paralyzable system over the range from $R_{20\%}/2$ (one-half of the 20 percent count loss count rate) to $R_{20\%}$ (the 20 percent count loss count rate) and thus shall be calculated in accordance with the following formula:

$$R_{obs} = Re^{-RT}$$

Where:
R_{obs} = observed count rate
R = true input count rate
T = dead time

1. Dead Time—The dead time T shall be calculated according to a modified two source measurement and reduced according to the formula:

$$T = \left(\frac{2R_{12}}{(R_1 + R_2)^2}\right) \ln\left(\frac{R_1 + R_2}{R_{12}}\right)$$

2. Observed—The observed count rate for a 20 percent loss ($R_{20\%}$) shall then be calculated from:

$$R_{20\%} = \frac{1}{T} \ln\left(\frac{10}{8}\right)\left(0.8\right) = \left(\frac{0.2231}{T}\right)\left(0.8\right) = \frac{0.1785}{T}$$

3. Acquisition of Data—The data shall be acquired by removing all collimators from the camera and exposing the UFOV to a source suspended near its axis at a distance greater than one meter as required to obtain the desired count rate. Record the count rate (R_1). Add a second source with activity within ±10 percent of the first in such a fashion that neither source obscures the other's view of the UFOV. Record R_{12}. Remove the first source and record R_2. For Tc-99m and other short lived sources repeat the procedure backwards and then average the count rate values. The count rate for both sources present, R_{12}, shall approximate the anticipated 20 percent loss count rate, within ±20 percent.
4. Reported Value—Report the input count rate for 20 percent loss.

3.4.7.3 MAXIMUM COUNT RATE

The maximum count rate shall be determined by setting the window to 20 percent. The camera shall be

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

slowly approached with about a 2mCi Tc-99m source centered over the UFOV, and the maximum observed count rate shall be recorded. Care must be taken to minimize scatter.

3.4.7.4 Measurement of Typical Input Versus Observed Count Rate Curve

As a class standard, the data for a typical input versus observed count rate curve shall be measured as follows (see Figure 3-2 for illustration):

1. Copper Absorber Plates—A number of equal thickness copper absorber plates individually calibrated for attenuation of Tc-99m gamma (approximately 2.5 millimeters thick) are placed between the source, in close proximity to the source, and the detector masked to the UFOV.
2. Source—The source shall be a Tc-99m point source, placed 1.5 meters in front of the center of the detector.
3. Shielding of Source—The source shall be shielded with no less than 6 millimeters of lead on the back and sides to prevent excessive background radiation or scatter.
4. Absorber Plates—The number of absorber plates to produce a background corrected count rate no greater than 2,500 cps shall be determined. From this count rate, knowing the calibration of each absorber and the decay rate of the source, any incident count rate can be obtained by removal of calculated number of absorber plates.
5. Foldover in Observed Count Rate Curve—At least 8 data points shall be measured between zero input count rate and that input count rate required to produce foldover in the observed count rate curve.
6. Typical Count Rate—The input rate versus observed rate points shall be graphed, curve fitted, and labeled as typical count rate.

3.4.7.5 System Spatial Resolution Measurements

The system spatial resolution measurements listed in 3.4.9 shall be performed for the UFOV only at an observed count rate of 75,000 cps through a 20 percent window and reported as class standard values.

3.4.7.6 System Flood Field Uniformity Measurements

The system flood field uniformity measurements listed in 3.4.4 shall be performed at an observed count rate of 75,000 cps through a 20 percent window and reported as class standard values.

3.4.8 Multiple Window Spatial Registration

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

3.4.8.1 Radionuclide

The radionuclide to be reported shall be Ga-67. If the camera has two windows the peaks at 93 keV and 296 keV shall be employed. For three windows the peak at 184 keV shall be additionally employed.

3.4.8.2 Total Count Rate

The total count rate shall not exceed 10,000 cps through each window. Each window shall be set to 20 percent.

3.4.8.3 Computation of GA-67 Source Displacement

A Ga-67 source, collimated through a hole 3 millimeters in diameter by a minimum of 6 millimeters in length, shall be placed at two points on each (X and Y) axis, acquired through the 2(3) windows, and the displacement in millimeters computed.

3.4.8.4 X-Axis Displacement Measurement

1. Digital Resolution—For the X-axis displacement measurement, the X-axis digital resolution shall be that obtained in a static multiposition study utilizing the scanning capabilities of the imaging device.
2. Peak Channel Count—The collimated source shall be placed on the +X axis, at the edge of the UFOV. Through each window, independently, at least 10,000 counts in the peak channel shall be acquired.
3. Peak Center(s) Displacement—The center of the peak for each window shall be determined as the average of the half maximum channels as described in 3.4.3.5. The displacement(s) (one or two) shall be the difference in the 296 keV (and 184 keV peak) center(s) from the center of the 93 keV peak.
4. Source—The source shall be moved to a point on the −X axis, at the edge of the UFOV. The measurement and calculation shall be repeated and knowing the distance between the two source locations, the two (or four) X displacement values for each point spread function shall be converted into millimeters.
5. Maximum X Registration Error—The largest of these 2 (or 4) X displacement values in millimeters shall be recorded as the maximum X registration error.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

3.4.8.5 Y-Axis Displacement Measurement

The Y-axis displacement values are measured via the procedure listed in 3.4.8.4 substituting Y-axis and X-axis, and the maximum Y registration error in millimeters is recorded.

3.4.8.6 Reporting of Displacement Factor

The larger of X and Y displacements shall be reported.

3.4.9 System Spatial Resolution With and Without Scatter

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

3.4.9.1 Radionuclide

The radionuclide to be employed for this measurement shall be Tc-99m. Any other radionuclide(s) employed for higher energy collimators shall be separately reported.

3.4.9.2 Count Rate

The count rate shall not exceed 10,000 cps through a 20 percent window. Measurements performed at any higher count rate shall be separately reported.

3.4.9.3 Sources

1. Composition of Sources—The sources shall consist of two capillary tubes, inside diameter ≤ 1.0 millimeters, length approximately the longest dimension of the UFOV.
2. Location of Sources—The sources shall be located at a distance of 100 millimeters from the face of the collimator. If resolution at other depths is reported, the depths shall be in 50 millimeter increments including 100 millimeters.
3. Measuring System Resolution Without Scatter—For measuring system resolution without scatter, no scattering medium shall be introduced between the capillary tubes and the collimator or behind the capillary tubes.
4. Measuring System Resolution With Scatter—For measuring system resolution with scatter, 100 millimeters of acrylic (e.g. Lucite™ or equivalent) shall be imposed between the capillary tube(s) and the collimator and 50 millimeters of acrylic (e.g. Lucite™ or equivalent) shall be placed behind the capillary tube(s). The acrylic (e.g. Lucite or equivalent) can be assembled from thinner pieces but must cover the entire UFOV.

3.4.9.4 Measurement of FWHM and FWTM Axes

1. Method—The measurement of each axis of FWHM and FWTM shall be performed with single capillary tube lying parallel to the axis of measurement with ± 1 millimeter.
2. Calibration Measurement—A second measurement for each axis shall be performed with the second capillary tube placed 50 millimeters away and parallel to the first tube. This measurement shall be for calibration purposes only.
3. Digital Resolution—The digital resolution of the system perpendicular to the tube shall be that normally employed in static imaging utilizing scanning capabilities of the imaging device. The digital resolution parallel to the tube(s) shall be no greater than 30 millimeters.
4. Peak Point Counts—At least 10,000 counts shall be collected in the peak point of each line spread function.
5. Calculation and Calibration Measurements of FWHM and FWTM—Using the measurement of step 1, above, the FWHM and FWTM shall be calculated by determining the half maximum and tenth maximum channels as the linearly interpolated values from the nearest two neighbors, using the largest channel value in each line spread function curve as the maximum. The channels shall be calibrated in millimeters by the measurement of step 2, above.
6. Reported FWHM and FWTM Values—The reported FWHM and FWTM values shall be those values measured within the UFOV and averaged for the X- and Y-axes. The use of scattering material, in accordance with 3.4.9.3, step 4, shall be clearly indicated.

3.4.10 System Sensitivity

As a class standard, the system sensitivity (camera and collimator) shall be measured for each collimator and reported in counts/(minute uCi) of the measured radionuclide for 20 percent windows.

3.4.10.1 Radionuclides

The radionuclides employed for these measurements shall be those for which the collimator is designed, and the collimator energy and isotope energy shall be reported.

3.4.10.2 Count Rates

The count rate shall not exceed 10,000 cps through a 20 percent window. Measurements performed at any higher count rate shall be separately reported.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

3.4.10.3 CALIBRATION OF SOURCE INTENSITY

The source intensity shall be accurately measured with a calibrated dose calibrator. The source shall be dispersed from the syringe into a shallow solution (approximately 3 millimeters in depth) in a 100 millimeter diameter sealed plastic dish, placed near the center of the collimator field of view 100 millimeters from the face of the collimator. The "empty" syringe shall be re-read in the dose calibrator and this reading subtracted from the original reading to obtain the amount of activity in the dish. Calibration methods shall be based on the NRC Regulatory Guide 10.8, or alternatively, NBS traceable calibrated sources shall be used as references, with appropriated half-life correction.

Counts/(minute.uCi) shall be reported. The identification of the collimator and camera shall be reported.

In this context, "counts" shall be defined as interactions in the crystal that fall within the analyzer window; therefore, field uniformity correction devices which alter the number of counts must be disabled.

3.4.11 EXTRINSIC COUNT RATE PERFORMANCE WITH SCATTER

One parameter is to be calculated and reported: observed count rate for a 20 percent count loss as a class standard. If circuitry is used to correct the output count rate for dead time losses, then such circuitry must be disabled in reporting this measurement. If such circuitry cannot be disabled, then this measurement must be reported as "not applicable".

3.4.11.1 RADIONUCLIDE

The radionuclide to be employed for this measurement shall be Tc-99m. Any other radionuclide(s) employed shall be reported separately. The analyzer window shall be 20 percent and centered on the photopeak. The phantom to be used is specified in 3.4.11.3.

3.4.11.2 COLLIMATION

The low energy parallel hole collimator of highest sensitivity shall be employed.

Any other collimators which are used shall be reported separately.

3.4.11.3 PHANTOM AND PROCEDURE

3.4.11.3.1 PHANTOM

The phantom shall consist of two Tc-99m sources of activity, within 10 percent of each other's doses, and in capped tubes which fit within 16.0 mm diameter by 12 cm long cavities. The tubular cavities shall be positioned 50 mm apart in a solid acrylic (e.g. Lucite™ or equivalent) phantom measuring 150 mm × 200 mm × 200 mm. Refer to Figure 2-6.

3.4.11.3.2 PROCEDURE

The activity in each tube shall be adjusted so that each has sufficient activity to produce, 1) 20,000 cps, and 2) 37,500 cps when counted separately in the phantom. The count rate with both sources present, R_{12}, must approximate the anticipated 20 percent count loss rate within ±20 percent. All values shall be permitted a tolerance of ± 10 percent. The volume of the source in each tube shall be approximately 10 ml.

3.4.11.4 20 PERCENT COUNT LOSS RATE WITH SCATTER

As a class standard, the observed count rate for 20 percent loss shall be calculated under scatter conditions at two observed count rates of approximately 40,000 cps and 75,000 cps on the assumption that the camera behaves as a purely paralyzable system over the range of count rates investigated. The behavior of paralyzable systems are approximated by the Poisson statistical distribution in accordance with the formula:

$$R_{obs} = Re^{-RT}$$

Where R_{obs} = observed count rate
R = true input count rate
T = dead time

3.4.11.5 ACQUISITION OF DATA

The data will be acquired with the tubular sources of activity parallel to the collimator and with the 200 mm × 200 mm face of the phantom closest to the sources against the surface of the collimator. The tubes shall be vertical (to lessen the chance of radioactive spills), with the midpoint between them at the center of the UFOV. A constant elapsed time between each of the source measurements described below shall be maintained to counteract the effects of radioactive decay.

1. Count Rate Source R_1—Place source 1 in the phantom and record the counts observed after imaging for 100 seconds.
2. Count Rate Source R_{12}—Add source 2 to the phantom and record the combined counts observed after imaging for 100 seconds.
3. Count Rate Source R_2—Remove source 1 and record the counts observed after imaging for 100 seconds.
4. Repeat the measurements—Repeat the above set of measurements in reverse order and average the respective results.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

3.4.11.6 CALCULATION OF DEAD TIME

1. The paralyzable dead time shall be calculated as:

$$T\ (\text{usec}) = \left(\frac{2R_{12}}{(R_1 + R_2)^2}\right) \ln\left(\frac{R_1 + R_2}{R_{12}}\right)$$

2. Observed Count Rate—The observed count rate for 20 percent input count rate loss ($R_{-20\%}$) shall then be reported as:

$$R_{-20\%} = .8\left(\frac{1}{T}\right) \ln\left(\frac{10}{8}\right) = \left(\frac{0.1785}{T}\right)$$

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Section 4

SCINTILLATION CAMERA BASED SINGLE PHOTON EMISSION COMPUTED TOMOGRAPHY (SPECT) PERFORMANCE MEASUREMENT STANDARDS

4.1 DEFINITIONS

The definitions contained in this Section apply only to single crystal scintillation cameras. Refer to 2.1. Refer to Section 1 for general definitions which apply to both single and multiple crystal scintillation cameras.

4.2 GENERAL

Refer to 2.2.1, 2.2.2, 2.2.3, 2.2.4 for general information on reported values, additional tests, corrections and traceability respectively.

4.3 TEST EQUIPMENT

A Co-57 flood source shall be used. Use phantom for SPECT performance measurements as described in 4.4.3.1. Five Co-57 point sources shall be positioned as described in 4.4.2.1.

4.4 TESTS

4.4.1 Angular Variation of Flood Field Uniformity and Sensitivity

As a class standard, the maximum change in flood field uniformity in the UFOV and maximum change in total sensitivity will be reported for a 360-degree rotation of the camera detector.

4.4.1.1 MEASUREMENT SETUP

The camera shall be collimated with the Tc-99m energy collimator generally recommended for SPECT. A Co-57 flood disc, larger in diameter than the UFOV, shall be securely attached to the collimator. The window shall be 20 percent and the activity of the Co-57 flood disc shall be such that no less than 10,000 and no more than 30,000 counts per second are detected through the 20 percent window.

4.4.1.2 DATA AQUISITION

Five flood images shall be taken. The first (0-degree) image shall be acquired with the detector pointing vertically down, and the four others shall be spaced 90 degrees apart. The 0-degree position is repeated.

Events shall be collected into a pixel matrix such that the pixel dimension is less than 20 mm square on a side and an average of 50,000 (±10 percent) counts are accumulated into each pixel while the detector is positioned at 0 degrees.

When rotating the detector in 90 degree increments about the rotation axis, 3 additional flood fields shall be acquired, each for the same acquisition time as the 0 degree flood. After the three floods have been acquired, the camera shall be returned to the original position (0°) and a fifth flood acquired for the same predetermined time. The five acquisitions shall be acquired consecutively with minimal time delays between them to reposition the camera and initiate a new acquisition.

4.4.1.3 REPORTED MAXIMUM SENSITIVITY VARIATION

The total counts in each of the five flood images shall be calculated. The maximum sensitivity variation shall be reported as:

$$\text{Maximum Sensitivity Variation} = \pm 100\% \frac{\text{Max. total counts} - \text{Min. total counts}}{\text{Max. total counts} + \text{Min. total counts}}$$

4.4.1.4 FULL FIELD MEASUREMENT AREA (FFMA)

Full field measurement area shall be that area as determined in 2.4.4.5.

4.4.1.5 FULL FIELD MEASUREMENT AREA PIXEL COUNT

For each of the five flood images, calculate total counts, average counts per pixel and average standard deviation per pixel (the square root of the average counts per pixel). (See C1.1.1).

4.4.1.6 CALCULATION

The total number of counts in each image shall be normalized to the number of counts in the first 0-degree flood. To normalize, each pixel value in the remaining four floods shall be multiplied in the remaining four floods by the ratio of the total counts in the first flood to the total counts in the flood being normalized.

For the purpose of determining if a significant change in flood uniformity occurred, the difference in counts per pixel between two floods shall be expressed in terms of the standard deviations which would be expected for a purely random distribution. The absolute value of the difference of the number of counts of each pixel shall be calculated by subtracting the number of counts in each individual pixel in one flood from the corresponding pixel in the other flood and taking the absolute value of the result. The value obtained shall be divided by the square

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

root of the sum of the squared standard deviations for those two floods that were calculated in 4.4.1.5.

The numbers of pixels in which the absolute difference is less than 1, 2, and 3 standard deviations, respectively, shall be calculated. Each of these whole numbers shall be divided by the total number of pixels in the flood and the resulting values recorded as percentage. The values for percentage of pixels exceeding 1, 2, and 3 standard deviations shall be reported. See C1.1.1.

4.4.1.7 Reported Uniformity Variations

The percentages of pixels which exceed 1, 2, and 3 standard deviations shall be calculated as described in 4.4.1.6 for the following flood subtractions:

First 0° — 90°
0° — 180°
0° — 270°
0° — Second 0°
90° — 270°

The maximum value of the five calculations for the fractions exceeding 1, 2, and 3 standard deviations, respectively, shall be recorded in Table 4-1. The appearance of greater fractions of pixels exceeding 1, 2, and 3 standard deviations than are typically published by the manufacturer shall be an indication of systematic nonuniformities as a function of rotation.

STANDARD DEVIATIONS	TYPICAL
1.00	
2.00	
3.00	

Table 4-1
FORMAT FOR REPORTING MAXIMA VALUES

4.4.2 Angular Variation of Spatial Position

As a class standard, report the maximum positional variation of a point source for a 360° rotation of the detector.

4.4.2.1 Measurement Setup

Five Co-57 point sources (nominally 1 mm) shall be securely attached to the Tc-99m collimator recommended for SPECT. One shall be located at the center of the field of view, with the 4 others spaced 90 degrees apart around the CFOV diameter, starting with the detector X-axis. The point sources shall be positioned one to two cm above the collimator which may be accomplished by fixing the sources on top of a plastic sheet of one to two cm thickness. The window shall be 20 percent with the count rate not to exceed 20,000 cps. The activity of the five point sources shall all be within ±20 percent of each other.

4.4.2.2 Image Angle

Five images shall be taken of the 5 points. The first (0-degree) image shall be acquired with the detector pointing vertically down, and the four others spaced 90 degrees apart. The 0-degree position is repeated.

The images shall be acquired into a 256 × 256 matrix to 100,000 total counts each.

4.4.2.3 Image Location

In each image, the location of each of the five points shall be calculated as the X, Y centroid of the distribution located within a 15 × 15 pixel area centered on the largest value in each peak.

4.4.2.4 Displacement Value

For each peak, the largest displacement from the 5 acquisitions shall be calculated by testing all 10 combinations and determining the largest displacement from:

$$\text{Displacement} = [(x_1 - x_1)^2 + (y_1 - y_2)^2]^{1/2}$$

The largest displacement for the 5 peaks shall be determined and calibrated by the position of the two peaks on the X-axis and the CFOV in the 0-degree image and reported in millimeters.

4.4.3 Reconstructed System Spatial Resolution

As a performance standard, the reconstructed spatial resolution of the SPECT sytem shall be measured.

4.4.3.1 Phantom

The phantom shall consist of an acrylic (e.g. Lucite™ or equivalent) cylinder with an inside diameter of 200 ± 5 mm; a wall thickness of 10 ± 2 mm and an inside length of 200 mm. See Figure 4-1.

1. Line Sources—Three Co-57 line sources, with the activity distributed in no larger than a 2 mm (nominally 1 mm) diameter, shall be placed within the cylinder oriented parallel to the cylinder's axis. One line source shall be on the axis of the cylinder (± 1.0 mm). The second and third line sources shall be 7.5 ± 0.3 cm from the axis and 90 degrees ± 5 degrees apart with respect to the central line source.
2. Content—The phantom shall be filled with water.

4.4.3.2 Measurement Set Up

The window shall be set to 20 percent and the activity of the line sources shall be such that the total count rate

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

through the 20 percent window does not exceed 20,000 counts per second. The phantom shall be transverse imaged with the axis of the phantom aligned with SPECT rotation axis within ± 5 mm and oriented such that the 2 off center line sources will lie along the X and Y axes of the reconstructed transverse slice. The radius of rotation shall be equal to 150 ± 5 mm. The data shall be collected into a 128 × 128 matrix using a X2 preprocess zoom. Alternatively, the data shall be acquired into a 256 × 256 matrix when the capability exists on the system without preprocess zoom.

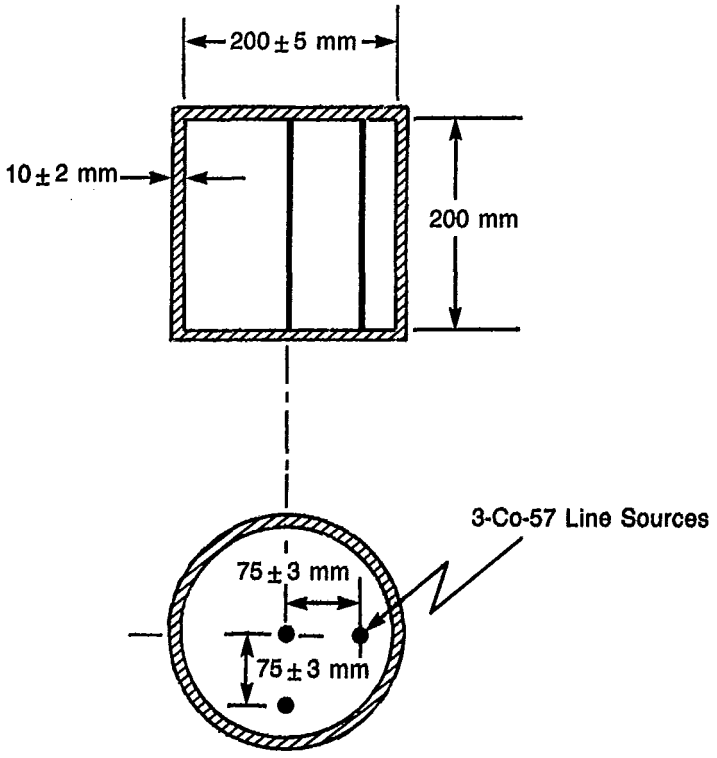


Figure 4-1
RECONSTRUCTED SYSTEM SPATIAL RESOLUTION

4.4.3.3 SLICES THROUGH PHANTOM

One transverse slice, 10 ± 3 mm in thickness, shall be reconstructed through the center of the phantom with specified reconstruction and correction techniques. A minimum of 250,000 counts shall be acquired into the reconstructed slice. Two additional transverse slices, 10 ± 3 mm in thickness, shall also be reconstructed, and centered about ± 40 mm from the center along the axis of rotation.

4.4.3.4 RECONSTRUCTED POINTS

Each of the three reconstructed points shall be isolated in a square region centered on the pixel with a maximum count that is at least four times the anticipated FWHM on a side. Each peak shall be integrated in the Y direction to determine an X line spread function (LSF) and integrated in the X direction to determine a Y LSF.

4.4.3.5 FULL WIDTH HALF MAXIMUM (FWHM)

For each peak, the FWHM in X and Y are calculated per 2.4.1.7, where the mm/pixel conversion factor is calculated from the average spacing between the center line source and each of the two peripheral line sources.

4.4.3.6 REPORTING SPECIAL RESOLUTION

Three FWHM values are reported. Referring to Figure 4-2, report the average FWHM radial value (in mm) of the 6 radial measurements for the two peripheral sources. Similarly, report the average tangential FWHM value of the 6 tangential measurements for the two peripheral sources. Also, the average of the 6 X or Y values for the 3 slices of the center source shall be reported.

4.4.4 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 system. 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. (See Appendix E.) (These two sentences approved as Authorized Engineering Information.)

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

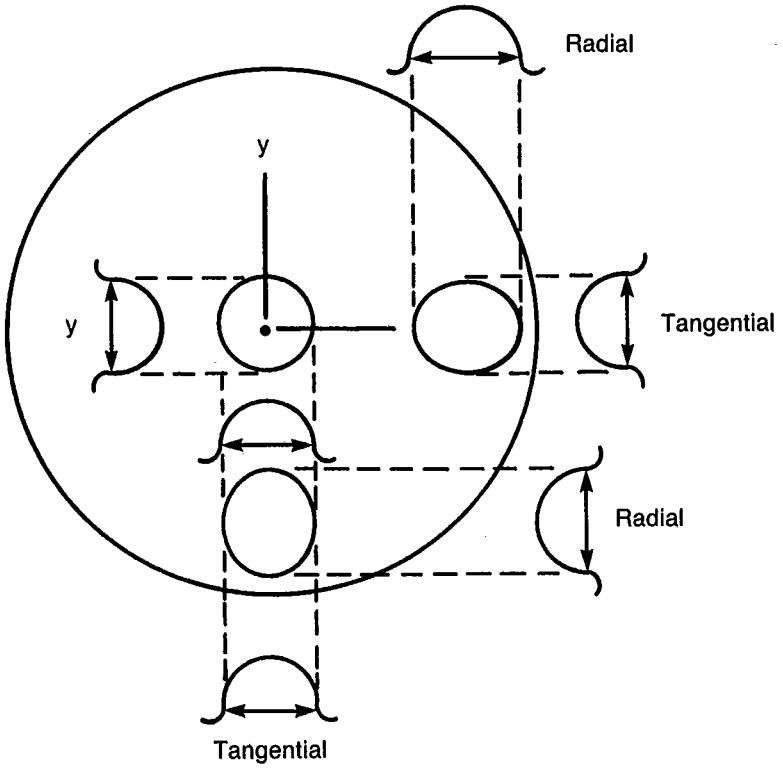


Figure 4-2
REPORTING SPATIAL RESOLUTION

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Section 5

TRACEABILITY DATA

5.1 INTRODUCTION

The user shall have some means to correlate the performance observed to the numeric data measured on the device by the manufacturer. The majority of tests in this Standards Publication cannot be duplicated without extensive instrumentation. The use of data and images supplied shall provide traceability via more simple and field reproducible techniques.

In this fashion, the user shall compare these images and data for acceptance testing, and then use these data to start a quality control program.

The manufacturer shall supply the user with data and images that correlate with the numeric data measured as specified in this Standards Publication. Data and images for class standard tests shall be optional. The manufacturer shall supply typical results. Standard tests listed in 5.8 can be exactly duplicated by the user.

5.2 GENERAL

Since images are produced by the entire system, including the display device, there MAY not exist an exact correlation between the images and the intrinsic detector data. (This sentence approved as Authorized Engineering Information.)

The manufacturer shall provide a complete description of the imaging parameters to enablethe user to create corresponding images.

The choice of imaging parameters not otherwise specified in this Standards Publication shall be at the discretion of the manufacturer.

The manufacturer shall be permitted to substitute alternative radionuclides for Tc-99m, Co-57, or Ga-67, and must specify those radionuclides employed.

5.3 INTRINSIC SPATIAL RESOLUTION

An image of a bar resolution pattern, corresponding to the intrinsic spatial test described in 2.4.1 shall be supplied by the manufacturer.

The pattern shall be imaged in two perpendicular orientations.

One set of bars must exceed the resolution capability of the detector.

The manufacturer shall fully describe the pattern, including allowed tolerances.

5.4 INTRINSIC ENERGY RESOLUTION

When the instrument is not capable of performing the intrinsic energy resolution test described in 2.4.3, then the electronic test point in the detector circuitry used to measure signals from the Intrinsic Energy Resolution Test shall be specified by the manufacturer.

If the system contains a device capable of producing spectral information, data for Tc-99m or Co-57 shall be supplied by the manufacturer.

5.5 INTRINSIC FLOOD FIELD UNIFORMITY

A flood field image corresponding to the intrinsic flood field uniformity test, described in 2.4.4 shall be supplied by the manufacturer.

The image shall be obtained with Tc-99m or Co-57 using a 20 percent analyzer window and a count rate not to exceed 30,000 cps.

5.6 INTRINSIC SPATIAL LINEARITY

An image of a linearity pattern, corresponding to the intrinsic spatial linearity test, described in 2.4.2., shall be supplied by the manufacturer.

The image shall be obtained with Tc-99 or Co-57 using a 20 percent analyzer window and a count rate less than 10,000 cps.

The phantom shall be imaged in two perpendicular orientations.

The manufacturer shall fully describe the pattern, including allowed tolerances.

5.7 MULTIPLE WINDOW SPATIAL REGISTRATION

A point source image, corresponding to the multiple window spatial test described in 2.4.7 shall be supplied by the manufacturer.

The image shall be obtained with Ga-67 and Co-57 or Ba-133 with 20 percent analyzer windows about the 93 keV and the 296 keV peaks and a count rate not to exceed 10,000 cps through each window.

The Ga-67 or Co-57 and Ba-133 source shall be collimated through a hole 5 millimeters in diameter by a minimum of 25 millimeters in length.

The point source shall be positioned and imaged at the edge of the CFOV as defined.

A single image shall contain the superimposed images taken along the 93 keV and 296 keV peaks at each source position. A reference image containing point source images using a single peak shall be supplied by the manufacturer.

5.8 TESTS DUPLICATED BY USER

Test duplicated by the user shall include those described in:

2.4.5—Point Source Sensitivity Variation (Class Standard)
2.4.6—Intrinsic Count Rate Performance
2.4.9—System Sensitivity (Class Standard)

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Section 6

TRACEABILITY DATA (MULTICRYSTAL CAMERAS)

6.1 INTRODUCTION

The user shall have some means to correlate the performance observed to the numeric data measured on the device by the manufacturer. the majority of tests in this Standards Publica-tion cannot be duplicated without extensive instrumentation. The use of data and images supplied shall provide traceability via more simple and field reproducible techniques.

In this fashion, the user shall compare these images and data for acceptance testing and then use the data to start a quality control program.

The manufacturer shall supply the user with data and images that correlate with the numeric data measured as specified in this Standards Publication. Data and images for class standard tests are optional. The manufacturer shall supply typical results.

6.2 GENERAL

Since images are produced by the entire system, including the display device, there willnot exist an exact correlation between the images and the intrinsic detector data. (This sentence approved as Authorized Engineering Information.)

The manufacturer shall provide a complete description of the imaging parameters to enable the user to create corresponding images.

The choice of imaging parameters not otherwise specified in this Standards Publication shall be at the discretion of the manufacturer.

The manufacturer shall be permitted to substitute alternate radionuclides for Tc-99m, Co-57, or Ga-67.

6.3 SYSTEM SPATIAL RESOLUTION

An image of a bar resolution pattern, corresponding to the system spatial test described in 3.4.9 shall be supplied by the manufacturer.

The image shall be obtained with Tc-99m and or Co-57 using a 20 percent analyzer window and a count rate less than 10,000 cps.

The phantom shall be imaged in two perpendicular orientations.

One set of bars must exceed the resolution capability of the detector.

The manufacturer shall fully describe the phantom, including allowed tolerances.

6.4 INTRINSIC ENERGY RESOLUTION

Since the system contains a device capable of producing spectral information, data for Tc-99m and Co57 shall be supplied by the manufacturer corresponding to the intrinsic energy resolution test described in 3.4.3.

6.5 SYSTEM FLOOD FIELD UNIFORMITY

A flood field image corresponding to the system flood field uniformity test described in 3.4.4 shall be supplied by the manufacturer.

The image shall be obtained with Tc-99m and/or Co-57 using a 20 percent analyzer window and a count rate not to exceed 30,000 cps.

6.6 SYSTEM SPATIAL LINEARITY

An image of a linearity pattern, corresponding to the system spatial linearity test described in 3.4.6 shall be supplied by the manufacturer.

The image shall be obtained with Tc-99m and/or Co-57 using a 20 percent analyzer window and a count rate less than 10,000 cps.

The phantom shall be imaged in two perpendicular orientations.

The manufacturer shall fully describe the pattern, including allowed tolerances.

6.7 MULTIPLE WINDOW SPATIAL REGISTRATION

A point source image, corresponding to the multiple window spatial test described in 3.4.8 shall be supplied by the manufacturer.

The image shall be obtained with Ga-67 or Co-57 and Ba-133 with 20 percent analyzer Zwindows and about the 92 keV and 296 keV peaks and a count rate not to exceed 10,000 cps through each window.

The Ga-67 or Co-57 and Ba-133 source shall be collimated through a hole 5 millimeters in diameter by a minimum of 25 millimeters in length.

The point source shall be positioned and imaged at the edge of the UFOV.

A single image shall contain the superimposed images taken along the 93 keV and 296 keV peaks at each source position.

A reference image containing point source images using a single peak shall be supplied by the manufacturer.

6.8 TESTS DUPLICATED BY USER

Tests duplicated by the user shall include those described in:

3.4.7 Intrinsic Count Rate Performance

3.4.10 System Sensitivity (Class Standard)

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Appendix A

RATIONALE FOR SINGLE CRYSTAL SCINTILLATION CAMERA TEST METHODS

(Approved as Authorized Engineering Information 1-17-1986.)

A.1.1 BACKGROUND

There is a heirachy of scintillation camera performance measurement needs. In temporal order, from manufacturer through daily clinical practice, the hierarchy is as follows:

1. Performance specification establishment and verification by manufacturer
2. Acceptance testing by user to verify (step 1), above
3. Routine clinical quality control

This appendix establishes standardized performance measurement and reporting technique to satisfy the need set forth in (step 1), above.

A.1.1 Traceability

The majority of the tests of Section 2 cannot be duplicated without extensive instrumentation.

As a consequence, the user should have some means to correlate the observed performance to the numeric data measured on the device by the manufacturer.

The data and images supplied should assist in providing this traceability via simpler field reproducible techniques.

A.1.2 Rationale for Chosen Measurement Techniques

The overall rationale for establishing these measurement techniques is to define techniques which may afford reproducible, quantitative measurements of performance. Subjective evaluations and GO/NO GO type tests have been rejected in favor of tests which should produce unequivocal quantitative measurements.

The following text addresses the rationale behind each of the tests of Section 2.

A.1.2.1 General Standards and Definitions Rationale

(Refer to 2.1.) Measurements for both UFOV and CFOV are reported since, particularly on wide field of view cameras, the CFOV may be more representative of the detector area of use for a large percentage of clinical studies.

(Refer to 2.2.1.) Performance standards should always be reported as "worst case", "better than", or "not to exceed" values, whereas class standards may be reported as typical.

A.1.2.2 Intrinsic Spatial Resolution Rationale

1. Choice of 1-millimeter Slit Width—(Refer to 2.4.1.3.) The choice of a 1-millimeter slit width was a deliberate tradeoff between sensitivity (counting time) and accuracy of the FWHM measurement. The use of a 1-millimeter slit may lead to an approximate 10 percent overestimation of FWHM for values of FWHM in the 2.5 to 3 millimeter range. By fixing the slit width at 1 millimeter the reported values of different manufacturers may be compared.
2. Alignment of Slit Pattern to Detector Axes—(Refer to 2.4.1.3.) Performing a least-squares linear fit to the centroid values for determining the center slit and the slope should allow adjustment of the phantom to within the 1 mm orientation criterion.
3. 0.1 FWHM Digital Resolution—(Refer to 2.4.1.4.) The digital resolution of 0.1 FWHM is necessary to accurately depict the line spread function. Lesser resolution would lead to a systematic error in calculated FWHM and FWTM.
4. Opposite Axis Digital Resolution Parallel to Slit—(Refer to 2.4.1.5.) The digital resolution parallel to the slits (less than or equal to 30 millimeters) is necessary or non-linearities and inevitable small rotations of the slit phantom could contribute errors to calculated FWHM and FWTM. This could also be achieved by masking the slit phantom in 30 millimeter segments. The 30 mm segments should be aligned along the slits such that the center segment on each slit is bisected by the diameter perpendicular to the slits, within ± 3 mm. This can be checked with a collimated point source.
5. 1000 Peak Channel Count—(Refer to 2.4.1.6.) Collecting 1000 counts in the peak channel of each line spread function measurement may not give sufficient statistical validity for local measurement; but, since 50 to 100 measurements should be averaged for the reported results, the FWHM and FWTM values reported have the statistical validity of a 50,000 to 10,000 count line spread function measurement.
6. Calculated Value at Center Slit—(Refer to 2.4.1.8.) Locating each calculated value at the center of each slit segment is necessary to allow selection of those slit segments lying within the CFOV.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

A.1.2.3 Intrinsic Energy Resolution Rationale

1. Use of keV Values—(Refer to 2.4.3.) Due to offset errors in analog to digital converters (ADC's), it is important that keV values rather than channel numbers should be used.
2. Additional Source Contribution—(Refer to 2.4.3.5.) Calibration using an additional source can be essential due to nonlinearities in NaI(T1), nonlinearities in processing electronics and zero channel errors in the ADC.

A.1.2.4 Intrinsic Flood Field Uniformity Rationale

1. Differential Uniformity—(Refer to 2.4.4.) Differential uniformity should be specified in addition to the more conventional integral uniformity as a method to better depict nonuniformities of a higher spatial frequency. RMS deviation has not been specified in this Standards Publication due to the potential for masking flood defects of a small physical extent.
2. Counts Stored per Pixel—(Refer to 2.4.4.5.) Storing 4000 counts per pixel leads to ± 1.58 percent standard deviation statistics. Particularly for the integral uniformity measurement, it is probable that several pixels could deviate by more than 3 standard deviations from the mean, or roughly ± 5 percent, since approximately 3000 samples should be examined. Since, for uniformity corrected systems, the integral uniformity specification could be comparable to ± 5 percent, therefore, the 9 point smooth should be required, which will reduce statistical uncertainty by a factor of 2.

   Since nonuniformities are typically several centimeters in extent, this smoothing should have a minimal detrimental effect on the uniformity measurement.

   For this reason, storage in a 64×64 matrix should be adequate to depict flood field nonuniformities. A larger matrix (128×128, for example) would require storing in excess of 50 million events without improvement in the characterization of typically existing nonuniformities.
3. Full Field Measurement—(Refer to 2.4.4.4.) A full field measurement area, which will be smaller than the UFOV otherwise defined, is defined below. This definition is necessary for determining uniformity since, outside this limit, the edge pixels of the 4 field would generate erroneously large integral and differential uniformity measurement errors due to the UFOV mask.

   Excluding 2 edge pixels around the UFOV corresponds to approximately 95 percent of the radius for a round detector. Excluding 8 edge pixels around the UFOV corresponds to approximately 75 percent of the radius for a round detector. A specific number of edge pixels were excluded rather than those outside a percentage of the UFOV linear dimensions in order to accomodate nonsquare/nonround UFOV geometry by excluding the same numbers of pixels for all UFOV geometries.
4. Search Range for Differential Uniformity—(Refer to 2.4.4.7.) The range of search for differential uniformity was picked to be 5 pixels which roughly corresponds to the radius of a photomultiplier tube.

   A larger search range would confuse the integral and differential uniformity, while a smaller range would not depict the typical higher spatial frequency flood field defects which typically occur with 1 cycle per photomultiplier tube.
5. Flood Field Uniformity—No quantitative flood field uniformity evaluation technique has been found to have a high degree of correlation to a trained observer's qualitative evaluations.

A.1.2.5 Intrinsic Spatial Linearity Rationale

1. Intent of Measurement—(Refer to 2.4.1.3 - 2.4.2.7.) The intent of this measurement technique was that the same set of measurements and calculations from 2.4.1.3 through 2.4.1.8 for spatial resolution may be employed for spatial linearity calculations.
2. Conversion Factors for mm Per Channel—(Refer to 2.4.1.8.) Four separate values of conversion factors for the millimeters per channel should be used for UFOV and CFOV in X and Y directions.

A.1.2.6 Intrinsic Count Rate Performance Rationale

1. Count Rate—(Refer to 2.4.6.) It is assumed that the manufacturer will test for and report 20 percent count loss rate and maximum count rate. The definition of the count rate curve and 75,000 cps resolution and uniformity as class standards imply that these measurements will not be performed on every camera.
2. 20 Percent Count Loss Rate—(Refer to 2.4.6.2.) The 20 percent count loss rate was chosen rather than the 10 percent loss rate. The 20 percent loss rate calculation is less subject to statistical error and better depicts the high count rate clinical situation.

   This measurement is a modification of the technique in *Journal of Nuclear Medicine,* Volume 19, 1978, Lim, C.B., Hoffer, P.B., Rollo, F.D., and Lilien, D.L. "Performance Evaluations of Recent Wide Field Scintillation Gamma Cameras," pp. 942-947.
3. Copper Absorber Technique—(Refer to 2.4.6.4.) The copper absorber technique for measurement of (incident) input versus observed count rate was

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

chosen over the decaying source method because it is far quicker to perform and, therefore, less subject to long term drift errors.

Since a copper sheet, ≤2.5 millimeters thick, is not readily available to ±1 percent thickness tolerance, it could be important to individually calibrate each copper absorber. Using the geometry of Figure 2-2 and a sufficiently weak Tc-99m source to produce ≤5000 cps, each absorber should be introduced and the ratio of count rates recorded.

Since the half value thickness for copper is approximately 3 millimeters for 140 keV photons, the absorbers should be 2.5 millimeters or less in thickness. This technique is described in *Journal of Nuclear Medicine*, Volume 19, 1978, Adams, R., Hine, G.J., and Zimmerman, C.D. "Dead time Measurements in Scintillation Cameras under Scatter Conditions Simulating Quantitative Nuclear Cardiography," pp. 538-544.

A.1.2.7 Multiple Window Spatial Registration Rationale

1. Collimated Ga-67 Source—(Refer to 2.4.7.) The collimated Ga-67 source was chosen rather than a bar or slit test pattern due to the impracticality of constructing a high energy phantom.
2. Avoidance of Positioning Errors—(Refer to 2.4.7.4.1.) With the source in each location, it is important to acquire data sequentially through each window, then move the source to avoid positioning errors.

A.1.2.8 System Spatial Resolution Rationale

1. Worst Case Intrinsic Resolution—(Refer to 2.4.8.) System spatial resolution is not intended to be measured for each camera, rather quoted for camera/collimator combination based on the worst case intrinsic resolution of the camera.
2. Single Capillary Tube Measurement for FWHM and FWTM—(Refer to 2.4.8.4.1.) The measurement for FWHM and FWTM is performed with a single capillary tube since, particularly for the scatter measurements, if both capillary tubes were present, the line spread function curves would overlap and render the FWTM calculation invalid.
3. Calculation of System Spatial Resolution—(Refer to 2.4.8.5.) Calculation of system spatial resolution, with and without scatter, for a changed intrinsic resolution is based on the validity of the expression:

$$R_s = (R_c^2 + (R_i/M)^2 + R^2_{scatt})^{1/2}$$

where: R_s = System spatial resolution (FWHM or FWTM)
R_c = Collimator resolution (FWHM or FWTM)
R_i = Instrinsic resolution (FWHM or FWTM)
M = Image magnification factor (image size/object size)
R_{scatt} = Scatter resolution

Without scatter, $R_{scatt} = 0$

With scatter, the collimator resolution determined in step 1 of 2.4.7.5 is actually:

$$(R_c^2 + R^2_{scatt})^{1/2}$$

In this manner, calculating new system spatial resolution values or changing intrinsic resolution should be equally valid for the scatter and nonscatter situation. The use of this for calibration of FWTM is susceptible to error due to the effect of septal penetration intrinsic to each collimator.

A.1.2.9 System Sensitivity Rationale

(Refer to 2.4.9.3.) The calibration of the dose calibrator to a NSB traceable source is important. The dose calibrator should be recalibrated for each radionuclide energy used.

A.1.2.10 Dead Time Approximation Equation

The dead time T for a paralyzable system should be determined by the following relationship from the two source measurement:

$$R_1 e^{N_1 T_1} + b e^{BT_B} + R_2 e^{N_2 T_2} + b e^{BT_B} = R_{12} e^{N_{12} T_{12}} + b e^{BT_B}$$

Where R_1, R_2, R_{12} are the observed count rates
N_1, N_2, N_{12} are respective true input count rates
T_1, T_2, T_{12}, T_B are the paralyzable dead times at the respective input count rate
b is the background count rate observed
B is the true background count rate (which is assumed to be identrical at input rates N_1, N_2, and N_{12})

a. The first approximation is that background is negligible compared to R_1, R_2, R_{12}; hence neglecting background:

$$R_1 e^{N_1 T_1} + R_2 e^{N_2 T_2} = R_{12} e^{N_{12} T_{12}}$$

b. The second assumption is that the dead time is constant within the range of the measurement, i.e., $T = T_1, = T_2, = T_{12}$; hence:

$$R_1 e^{N_1 T} + R_2 e^{N_{12} T}$$

c. The third approximation is that the two sources are nearly equal, hence:

$$R_1 \cong R_2;\ N_1 \cong N_1 \cong \frac{N_{12}}{2}$$

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

$$(R_1 + R_2)\, e^{NT} = R_{12} e^{2NT}$$

$$\text{Thus} \quad T = \frac{1}{N} \ln \left(\frac{R_1 + R_2}{R_{12}} \right)$$

Substituting this into the equation:

$$N_{12} = 2N = (R_1 + R_2)\, e^{NT}$$

produces

$$N = \frac{(R_1 + R_2)^2}{2R_{12}}$$

$$\text{thus} \quad T = \frac{2R_{12}}{(R_1 + R_2)^2} \ln \left(\frac{R_1 + R_2}{R_{12}} \right)$$

A.1.2.11 MINIMAL BACKGROUND

Because the approximation for calculating dead time requires assuming the background to be negligible, it is important for the measurement's accuracy. Therefore, the measurement should be performed with the least background possible.
(Refer to 2.4.10.3.) It is important to keep the background at low level since the formula for calculating dead time assumes that the background is negligible.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Appendix B

RATIONALE FOR MULTIPLE SCINTILLATION CRYSTAL CAMERA TEST METHODS

(Approved as Authorized Engineering Information 1-17-1986.)

B.1 BACKGROUND

There is a hierarchy of scintillation camera performance measurement needs. In temporal order, from manufacturer through daily clinical practice, the hierarchy is as follows:

1. Performance specification establishment and verification by manufacturer
2. Acceptance testing by user to verify step 1, above
3. Routine clinical quality control.

This appendix establishes standardized performance measurement and reporting techniques to satisfy the need set forth in step 1, above.

B.1.1 Traceability

The majority of the tests of Section 3 cannot be duplicated without extensive instrumentation.

As a consequence, the user should have some means to correlate the observed performance to the numeric data measured on the device by the manufacturer.

The data and images supplied should assist in providing this treaceability via simpler field reproducible techniques.

B.1.2 Rationale for Chosen Measurement Techniques

The overall rationale in establishing these measurement techniques is to define techniques which may afford reproducible, quantitative measurements of performance. Subjective evaluations and GO/NO GO type tests have been rejected in favor of tests which should produce unequivocal quantitative measurements.

The following text addresses the rationale behind each of the tests of Section 3.

B.1.2.1 General Standards and Definitions Rationale

(Refer to 3.2.1.) Performance standards should always be reported as "worst case", 'better than", or "not to exceed" values, whereas class standards may be reported as typical.

B.1.2.2 Intrinsic Energy Resolution Rationale

1. Use of keV Values—(Refer to 3.4.3.) Due to offset errors in analog to digital converters (ADC's), it is important that keV values rather than channel numbers are used.
2. Alternate Source Contribution—(Refer to 3.4.3.) Calibration using an additional source is recommended due to nonlinearities in NaI (T1), nonlinearities in processing electronics and zero channel errors in the ADC.

B.1.2.3 System Field Uniformity Rationale

1. Differential Uniformity—(Refer to 3.4.4.6.) Differential uniformity is specified in addition to the more conventional integral uniformity as a method to better depict nonuniformities of a higher spatial frequency.

   RMS deviation has not been specified in this Standards Publication due to the potential for masking flood defects of a small physical extent.
2. Search Range for Differential Uniformity—(Refer to 3.4.4.6.) The range of search for differential uniformity was picked to be 3 pixels.

   A larger search range would confuse integral and differential uniformity, while a smaller range would not depict the typical higher spatial frequency flood field defects.
3. Flood Field Uniformity—No quantitative flood field uniformity evaluation technique has been found to have a correlation coefficient greater than 0.5 to trained observers qualitatively evaluating flood fields.

B.1.2.4 System Spatial Linearity Rationale

1. Conversion Factors for mm Per Channel—(Refer to 3.4.6.8.) Four separate values of conversion factors for the millimeters per channel should be used for UFOV in X and Y directions.

B.1.2.5 Intrinsic Count Rate Performance Rationale

1. Count Rate—(Refer to 3.4.7.) It is assumed that the manufacturer will test for and report 20 percent count loss rate and maximum count rate. The definition of the count rate curve and 75,000 cps resolution and uniformity as class standards imply that these measurements will not be performed on every camera.
2. 20 Percent Count Loss Rate—(Refer to 3.4.7.2.) The 20 percent count loss rate was chosen rather than the 10 percent loss rate. The 20 percent loss rate calculation is less subject to statistical error and better depicts the high count rate clinical situation.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

This measurement is a modification of the technique set forth in Ralph Adams, Gerald J. Hine, C. Duane Zimmerman: "Dead time measurements in scintillation cameras under scatter conditions simulating quantitative nuclear cardiography." *Journal of Nuclear Medicine* 19: 538-544, 1978.

3. Copper Absorber Technique—(Refer to 3.4.7.4.) The copper absorber technique for measurement of (incident) input versus observed count rate was chosen over the decaying source method as being far quicker to perform and, therefore, less subject to long term drift errors.

   Since a copper sheet, ≤2.5 millimeters thick, is not readily available to ±1 percent thickness tolerance, it may be important to individually calibrate each copper absorber. Using the geometry of Figure 3-2 and a sufficiently weak Tc-99m source to produce ≤5000 cps, each absorber should be introduced and the ratio of count rates recorded.

   Since the half value thickness for copper is approximately 3 millimeters for 140 keV photons, the absorbers should be 2.5 millimeters or less in thickness. This technique is described in Chun Bin Lim, Paul B. Hoffer, F. David Rollo, David L. Lilien: "Performance evaluation of recent wide field scintillation gamma cameras." *Journal of Nuclear Medicine* 19: 942-947, 1978.

B.1.2.6 MULTIPLE WINDOW SPATIAL REGISTRATION RATIONALE

1. Collimated Ga-67 Source—(Refer to 3.4.8.3.) The collimated Ga-67 source was chosen rather than a bar or slit test pattern due to the impracticality of constructing a high energy phantom.
2. Avoidance of Positioning Errors—(Refer to 3.4.8.4.) With the source in each location, it is important to acquire data sequentially through each window, and then move the source to avoid positioning errors.

B.1.2.7 SYSTEM SPATIAL RESOLUTION RATIONALE

1. Worst Case Intrinsic Resolution—(Refer to 3.4.9.) System spatial resolution is not intended to be measured for each camera, but rather to be quoted for camera/collimator combination based on the worst case intrinsic resolution of the camera.
2. Single Capillary Tube Measurement for FWHM and FWTM—(Refer to 3.4.9.4.) The measurement for FWHM and FWTM is performed with a single capillary tube since, particularly for the scatter measurements, if both capillary tubes were present, the line spread function curves would overlap and render the FWTM calculation invalid.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Appendix C

RATIONALE FOR SCINTILLATION CAMERA BASED SINGLE PHOTON (SPECT) PERFORMANCE MEASUREMENT STANDARDS

(Approved as Authorized Engineering Information 1-17-1986.)

C.1 BACKGROUND

There is a need to apply performance standard measurements to scintillation camera and computer systems which are designed for single photon emission computed tomography. The needs are the same as for measuring intrinsic performance of the scintillation camera:

1. Performance specification establishment and verification by manufacturer
2. Acceptance testing by user to verify step 1, above
3. Routine clinical quality control.

In the case of SPECT performance measurements, however, assuring the intrinsic performance of the camera alone is not sufficient because the system performance also depends on the computer software (reconstruction algorithm, attenuation correction, and such), gantry control, and possibly environmental effects such as magnetic fields (Earth's or other).

C.1.2 Rationale

C.1.2.1 Angular Variation of Flood Field Uniformity and Sensitivity

1. This measurement is designed to identify uniformity and sensitivity variations with respect to rotation which may affect the quality of tomographic reconstruction. Such variation may be introduced by magnetic fields or the presence of external radiation sources. If such variations are present, they may indicate an undesirable environment for tomographic acquisition. It should be performed because the local magnetic field acting upon the PMT's in the detector head can perturb the detector signals when the detector position is changed. It should be noted that stray magnetic fields from motors, focus coils and other equipment may produce misleading results.
2. Explanation of Calculations in 4.4.1.5
   For Full Field Measurement Areas $FFMA^A$ and $FFMA^B$:

$$\text{Total counts in flood A} = \text{(Formula)} \sum_{ij} C^A_{ij}$$

$$\text{Total counts in flood B} = \text{(Formula)} \sum_{ij} C^B_{ij}$$

$$\text{Average counts per pixel flood A} = \overline{C^A} = \frac{C^A{}_{TOT}}{\#\text{ of pixels in } FFMA^A}$$

$$\text{Average counts per pixel flood B} = \overline{C^B} = \frac{C^B{}_{TOT}}{\#\text{ of pixels in } FFMA^B}$$

$$\text{Average standard deviation per pixel in flood A} = \text{s.d.}^A = \left(\overline{C^A}\right)^{1/2}$$

$$\text{Average standard deviation per pixel in flood B} = \text{s.d.}^B = \left(\overline{C^B}\right)^{1/2}$$

3. Explanation of Calculations in 4.4.1.6
   Flood Normalization—The five flood images acquired are labeled A,B,C,D and E, with A being the first flood (0-degree flood).
   For Floods B-E, the normalized counts are calculated

$$N^X_{ij} = C^X_{ij}\left(\frac{C^A_{TOT}}{C^X_{TOT}}\right)$$

where N^X_{ij} is the normalized counts in pixel i,j of Flood X (B-E)

C^X_{ij} is the original counts in pixel i,j of Flood X

C^X_{TOT} is the total counts in the UFOV of Flood X

Flood Subtraction—For an example calculation two floods being compared are floods A and B.
Calculate the difference between counts in pixel i,j in Flood A & B.

$$\text{Difference} = \left(C^A_{ij} - N^B_{ij}\right) \quad \text{for each pixel i,j}$$

The absolute value of the difference is

$$\left|C^A_{ij} - N^B_{ij}\right| \quad = \text{for each pixel i,j}$$

The expected standard deviation for that difference is approximately equal to

$$\text{s.d.}_{A\text{-}B} = \left((\text{s.d.}^A)^2 + (\text{s.d.}^A)^2\right)^{1/2} = \left(\overline{C^A} + \overline{C^B}\right)^{1/2}$$

since the individual pixel values should be close to the average for uniform floods (± 10 percent depending on the uniformity of the flood source).
Therefore, for each pixel (ij), the difference in units of expected standard deviation is:

$$D^{A\text{-}B}_{ij} = \frac{C^A_{ij} - N^B_{ij}}{(\overline{C^A} + \overline{C^B})^{1/2}}$$

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Report Percentage:

$$\frac{\text{number of } D_{ij}^{A-B} > \text{ for all ij in FFMA}}{\text{number of pixels in FFMA}} \times 100$$

and similarly for $D_{ij}^{A-B} > 2$ and $D_{ij}^{A-B} > 3$.

C.2 RECONSTRUCTED SYSTEM SPATIAL RESOLUTION

C.2.1 Rationale

The intention of this test is to provide a benchmark point for reconstructed system spatial resolution. A benchmark should allow the user to compare his system performance to that specified by the manufacturer to insure that the system is functioning properly. It is not intended that the resolution measured using this procedure be either typical or worst case for clinical tomographic procedures, but the collimator, filtering, and reconstruction parameters should not be atypical of clinical tomography.

C.2.2 Discussion

The spatial resolution exhibited in a reconstructed tomographic image is a function of many parameters or procedures, such as: intrinsic camera resolution, collimator resolution, radius of rotation, scatter within the object being imaged, pixel size into which the planar images are recorded, filtering of the planar images, reconstruction algorithm, post reconstruction filtering, reconstruction matrix size, attenuation corrections, count density, energy peaking, and others. Clearly, a straightforward comparison of differenct SPECT systems is not possible without understanding and accounting for the differences in these parameters or procedures. Reconstructed system spatial resolution can be changed (improved) by both physical and mathematical parameters or procedures, but for an optimized system, these changes may degrade some other clinically relevant performance parameter. An example would be if a collimator with very good resolution were used at the expense of sensitivity. In this case, very good reconstructed spatial resolution might be measured for a fixed total number of counts, but that resolution might not be obtainable in a reasonable clinical procedure because of excessively long acquisition times. Less obvious examples might include filtering which optimizes resolution for the method described in this standard procedure but would be excessively noisy for filtering clinical images. Another such example is actually built into the procedure, that is, using a 2x preprocess zoom when acquiring the data into a 128 × 128 matrix. The effect of this is to have 256 × 256 resolution on the central region of the field of view. This procedure was intentionally done in order that the reconstructed points would have a sufficient number of pixels within their FWHM to be measurable without using sophisticated peak fitting algorithms applied to a few data points.

Summarizing, the clinical user should bear several points in mind when comparing the recon-structed system spatial resolution with either different systems of clinical resolution values. First, the test procedure represents a high count density point source in a very fine pixel matrix (equivalent to 256 × 256). Second, the image processing and filtering can strongly affect the result and, therefore, should be the same as those applied to obtain the results to which they are being compared. Lastly, the effects of collimator resolution and radius of rotation on the reconstructed spatial resolution should be taken into account for any intercomparison. The measured resolution does not necessarily reflect the clinical resolution because of the above factors.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Appendix D

SPECT SYSTEM PERFORMANCE MEASUREMENT REPORTING FORM

(Approved as Authorized Engineering Information 1-17-1986.)

Camera Manufacturer:

Camera Model:

Computer Manufacturer:

Computer Model:

NEMA CLASS STANDARD SPECIFICATION

Angular Variation of Flood Field Sensitivity	xx.x%	
Angular Variation of Flood Field Uniformity		
Pixels Beyond One Std. Dev.	xx.x%	Ideal—33.0%
Pixels Beyond Two Std. Dev.	xx.x%	5.0%
Pixels Beyond Three Std. Dev.	xx.x%	0.6%
Angular Variation of Spatial Registration	xx.x mm	

NEMA PERFORMANCE STANDARD SPECIFICATION

Reconstructed System Spatial Resolution		Collimator—
		No. of Views—
FWHM at Center	xx.x mm	Reconstruction
Radial FWHM at 75 mm	xx.x mm	Algorithm—
Tangential FWHM at 75 mm	xx.x mm	Filter—

Table D-1
REPORTING FORM

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

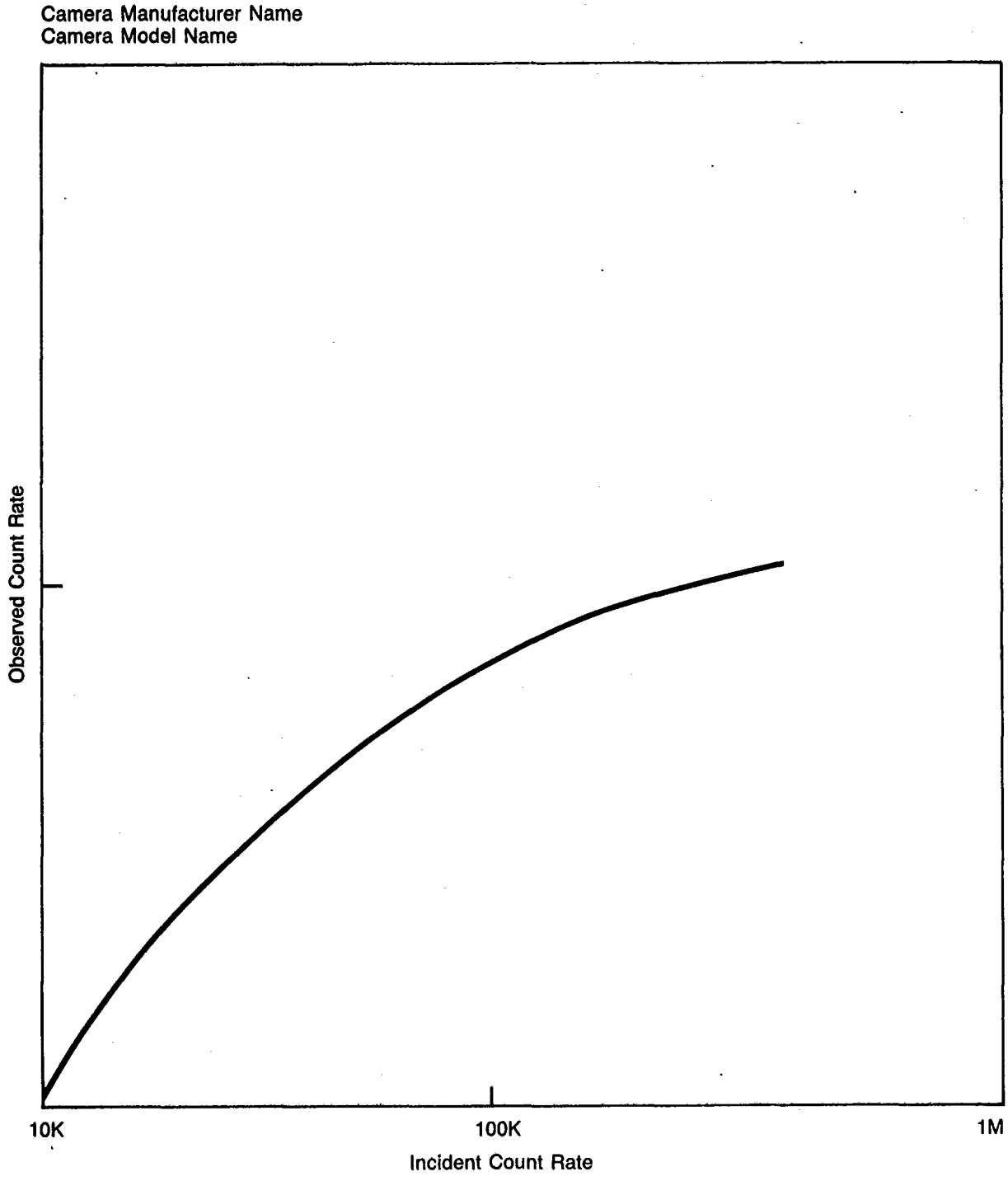


Figure D-1
TYPICAL INCIDENT VERSUS OBSERVED COUNT RATE CURVE

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Appendix E

RECONSTRUCTED (RELATIVE IMAGE NOISE) IMAGE UNIFORMITY

(Approved as Authorized Engineering Information 1-17-1986.)

Methods that will correlate with current visualization are being researched.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

Appendix F

COLLIMATOR SENSITIVITY CALIBRATION NOTE

(Approved as Authorized Engineering Information 1-17-1986.)

Having established the absolute sensitivity of one collimator and camera combination, for other collimators, it is permissible to perform relative sensitivity measurements and calibrate those measurements with respect to the original absolute measurement.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

September 1984

NEMA STANDARDIZATION

The purpose of NEMA Standards, their classification and status are set forth in certain clauses of the NEMA Bylaws, which are quoted 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 its particular need. 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.

(Bylaw—Art. V, Sec. 1)

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, construction, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

(Bylaw—Art. V, Sec. 2, Subsection A)

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.

(NEMA Policy Memorandum 84-2, dated June 7, 1984)

Classes of Standards

National Electrical Manufacturers Association Standards are of two classes:

1. NEMA Standard, which relates to a product commercially standardized and subject to repetitive manufacture, which standard has been approved by at least 90 percent of the members of the Subdivision eligible to vote thereon;
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, which standard has been approved by at least two-thirds of the members of the Subdivision eligible to vote thereon.

(Bylaw—Art. V, Sec. 2, Subsection B)

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.

(Bylaw—Art. V, Sec. 6, 1st Sentence)

Official Standards Proposal

An Official Standards Proposal is an official draft of a proposed standard which is formally recommended to an outside organization(s) for consideration, comment and/or approval.

(Bylaw—Art. V, Sec. 4, Subsection A)

Identification of Status

Standards in NEMA Standards Publications are identified in the foreword or following each standard as "NEMA Standard" or "Suggested Standard for Future Design." These indicate the status of the standard. These words are followed by a date which indicates when the standard was adopted in its present form by the Association.

The material identified as "Authorized Engineering Information" and "Official Standards Proposal" is designated similarly.

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale

NUCLEAR SECTION
OF THE
NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION

MEMBER COMPANIES

ADAC Laboratories
San Jose, CA 95138

Baird Corporation
Bedford, MA 01730

Capintec, Inc.
Ramsey, NJ 07446

Dimensional Medicine, Inc.
Minnetonka, MN 55343

Elscint, Inc.
Boston, MA 92215

General Electric Company
Medical Systems Division
Milwaukee, WI 53201

Victoreen, Inc.
Nuclear Associates Division
Carle Place, NY 11514

Picker International, Inc.
Highland Heights, OH 44143

Raytheon Medical Systems
Melrose Park, IL 60160

Siemens Gammasonics, Inc.
Des Plaines, IL 60018

Technicare Corporation
Solon, OH 44139

Toshiba America, Inc.
Toshiba Medical Systems Division
Tustin, CA 92680

Copyright National Electrical Manufacturers Association
Provided by IHS under license with NEMA
No reproduction or networking permitted without license from IHS
Not for Resale