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STANDARDS PUBLICATION / NO. NU 1-1980

nema

performance measurements of scintillation cameras

NEMA

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PERFORMANCE MEASUREMENTS OF SCINTILLATION CAMERAS

Foreword

User input has been considered in the development of this Standards Publication.

This 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.

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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.* These standards do not establish minimum performance levels.

Elaborate measurement equipment is required in order to accomplish the purpose of these standards: 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. Because of the use of this equipment, these standards are not intended for acceptance testing at installation, user quality assurance, or for use as a user quality control procedure. The concept of traceability, established in Appendix A, par. NU 1-A1.01.A, and Appendix B, par. NU 1-B1.01.A, however, provides the means for relating the manufacturer's performance measurements to acceptance tests.

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 energy resolution.
Flood field uniformity.
Spatial linearity.
Count rate performance.
Multiple window spatial registration.
System spatial resolution.
System sensitivity.

Inclusions—Types of medical radionuclide instruments included in these standards are:

1. Single crystal scintillation cameras.
2. Multiple crystal scintillation cameras.

Exclusions—Types of medical radionuclide devices not included in these standards are:

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

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Part 1
GENERAL DEFINITIONS

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

NU 1-1.01 ANALYZER WINDOW

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

NEMA Standard 1-17-1980.

NU 1-1.02 CLASS STANDARD

A 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. Usually the parameter is of auxiliary interest and is a subset of a measured standard.

NEMA Standard 1-17-1980.

NU 1-1.03 DETECTOR

A detector is a component of the scintillation camera which is designed to accept incident gamma radiation for the purpose of imaging and counting.

NEMA Standard 1-17-1980.

NU 1-1.04 DIFFERENTIAL LINEARITY

Differential linearity is a parameter of a scintillation camera which characterizes the amount of positional distortion or displacement over a known distance caused by the camera with respect to incident gamma events entering the detector.

NEMA Standard 1-17-1980.

NU 1-1.05 DIFFERENTIAL UNIFORMITY

Differential uniformity is a parameter of a scintillation camera 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.

NEMA Standard 1-17-1980.

NU 1-1.06 DIGITIZATION RESOLUTION

Digitization resolution is the size of the channels utilized in the conversion of analog scintillation camera signals into discrete bits of data for quantitative measurement.

NEMA Standard 1-17-1980.

NU 1-1.07 ENERGY RESOLUTION

Energy resolution is a parameter of a scintillation camera which characterizes its ability to accurately isolate and identify the photopeak energy from a radioisotopic source. This parameter in a scintillation camera determines its ability to distinguish between primary peak gamma events and those from secondary or scattered events.

NEMA Standard 1-17-1980.

NU 1-1.08 FOLDOVER

Foldover is a characteristic of a scintillation camera when it is counting beyond its maximum count rate. Additional activity causes a decrease in the observed count rate instead of an increase.

NEMA Standard 1-17-1980.

NU 1-1.09 FULL WIDTH AT HALF MAXIMUM (FWHM)

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

NEMA Standard 1-17-1980.

NU 1-1.10 FULL WIDTH AT TENTH MAXIMUM (FWTM)

Full width at tenth maximum is the measure of the spread of a peak point, or line response curve, across locations 90 percent down on each side from the peak amplitude.

NEMA Standard 1-17-1980.

NU 1-1.11 INCIDENT RATE

The incident rate is the independently measured or calculated rate of gamma events entering the scintillation camera detector.

NEMA Standard 1-17-1980.

NU 1-1.12 INTEGRAL LINEARITY

Integral linearity is a parameter of a scintillation camera which characterizes its ability to present X-Y data without positional distortion, accurately representing the incident gamma distribution.

NEMA Standard 1-17-1980.

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NU 1-1.13 INTRINSIC

Intrinsic means the basic scintillation camera without variables which may change its inherent characteristics, especially without collimator or display device.

NEMA Standard 1-17-1980.

NU 1-1.14 LINEAR INTERPOLATION

Linear interpolation is the calculated values between two known points that will fall on a straight line connecting the two known points. The value halfway between the known points will be the arithmetic average of the two known point values.

NEMA Standard 1-17-1980.

NU 1-1.15 OBSERVED COUNT RATE

The observed count rate is the counts per unit time resulting from gamma events incident on the detector as determined from the scintillation camera's scaler or count rate measuring instrument.

NEMA Standard 1-17-1980.

NU 1-1.16 PERFORMANCE

Performance is the characteristic function or operational parameters of a scintillation camera with regard to its effectiveness in imaging distributed gamma events.

NEMA Standard 1-17-1980.

NU 1-1.17 PHOTOPEAK

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

NEMA Standard 1-17-1980.

NU 1-1.18 PIXEL

A pixel is the smallest image element in a X-Y digital memory. It represents a known X-Y location and contains count information integrated from that X-Y area.

NEMA Standard 1-17-1980.

NU 1-1.19 SCATTER

Scatter is the radiation from a gamma source that has been degraded to a lower energy state due to its travel and interaction in a medium, i.e., water and Lucite™.

NEMA Standard 1-17-1980.

NU 1-1.20 SENSITIVITY

Sensitivity is a parameter of a scintillation camera which characterizes its ability to efficiently convert a source of incident gamma rays of known activity to count and position data for imaging.

NEMA Standard 1-17-1980.

NU 1-1.21 SPATIAL RESOLUTION

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

NEMA Standard 1-17-1980.

NU 1-1.22 SPECTRUM

The spectrum is the curve of the response of the scintillation camera to incoming gamma radiation measured as counts versus energy in keV.

NEMA Standard 1-17-1980.

NU 1-1.23 STANDARD DEVIATION

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

NEMA Standard 1-17-1980.

NU 1-1.24 TEST PATTERN

A 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.

NEMA Standard 1-17-1980.

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Part 2
SINGLE CRYSTAL SCINTILLATION CAMERA TEST METHODS

DEFINITIONS

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

NU 1-2.01 USEFUL FIELD OF VIEW (UFOV)

The useful field of view (UFOV) is a circular area with a diameter that is the largest inscribed circle within the collimated field of view.

NEMA Standard 1-17-1980.

NU 1-2.02 CENTRAL FIELD OF VIEW (CFOV)

The central field of view (CFOV) is a circular area with a diameter that is 75 percent of the diameter of the UFOV. The CFOV is centered on the center of the UFOV.

NEMA Standard 1-17-1980.

GENERAL

NU 1-2.10 REPORTED VALUES

In stating specifications, all reported values shall be labeled as "worst case", "better than", "not to exceed" and UFOV or CFOV indicated, except where otherwise defined in these standards.

NEMA Standard 1-17-1980.

NU 1-2.11 ADDITIONAL TESTS

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

NEMA Standard 1-17-1980.

NU 1-2.12 CORRECTION DEVICES

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

NEMA Standard 1-17-1980.

NU 1-2.13 TRACEABILITY

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

NEMA Standard 1-17-1980.

TEST EQUIPMENT AND MINIMUM INSTRUMENTATION REQUIREMENTS

NU 1-2.20 MULTICHANNEL ANALYZER (MCA) SYSTEMS

Multichannel analyzer (MCA) systems 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. 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 10000 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 $\leqslant 0.1$ FWHM = 1024 channels) must have differential linearity no worse than plus or minus 3 percent.

The ADC used for the low resolution axis (digitization to 8, 16, or 64 channels) must have differential linearity no worse than plus or minus 1 percent at 64-channel resolution.

NEMA Standard 1-17-1980.

NU 1-2.21 ADDITIONAL TEST EQUIPMENT

The following additional test equipment shall be required:

(1) Slit mask as shown in Fig. 2-1.
(2) Lead ring to mask to the UFOV.
(3) Source holder for count rate performance as shown in Fig. 2-2.
(4) A number of copper absorbers as shown in Fig. 2-2.

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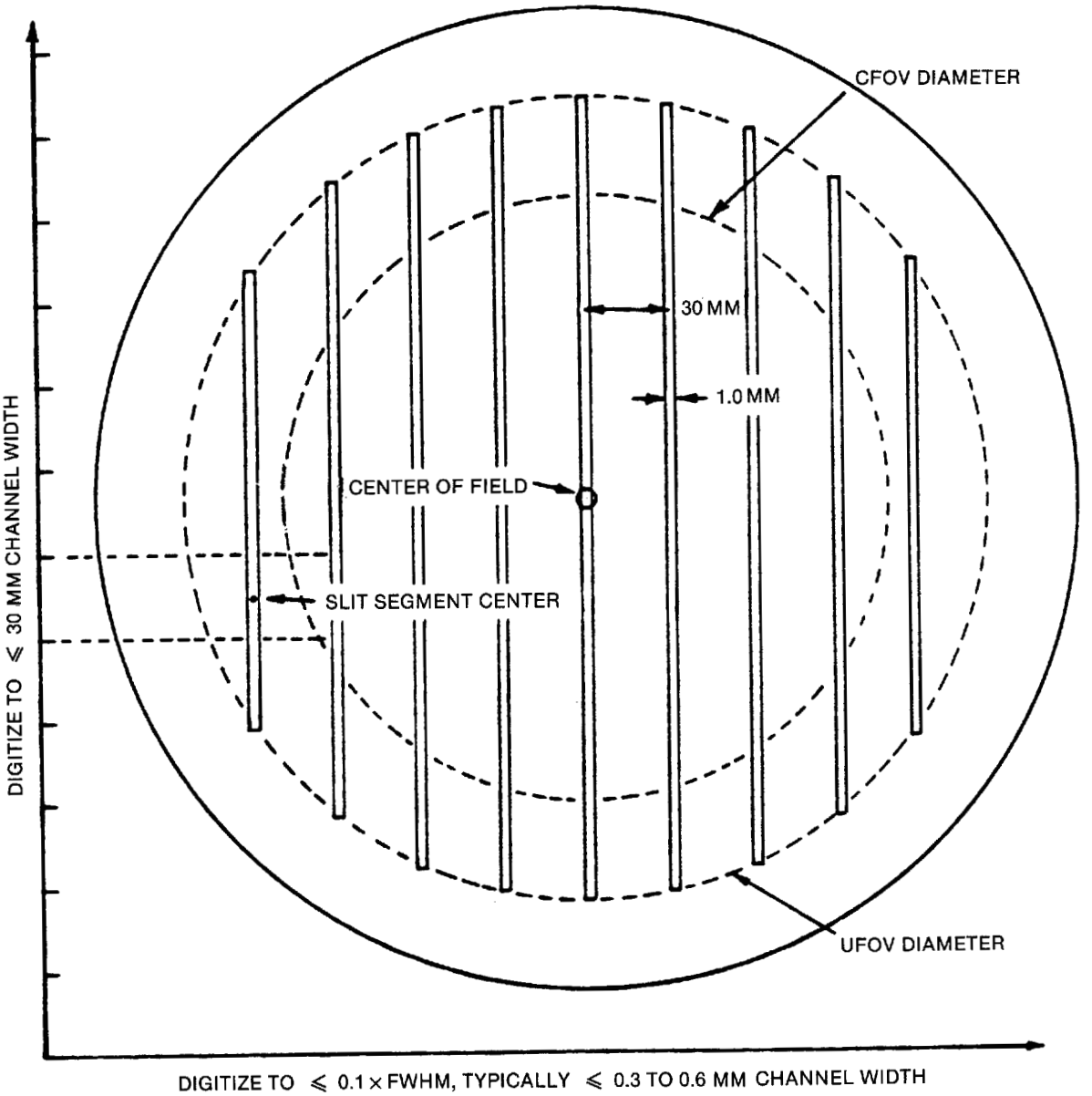


Fig. 2-1
RESOLUTION AND LINEARITY PHANTOM

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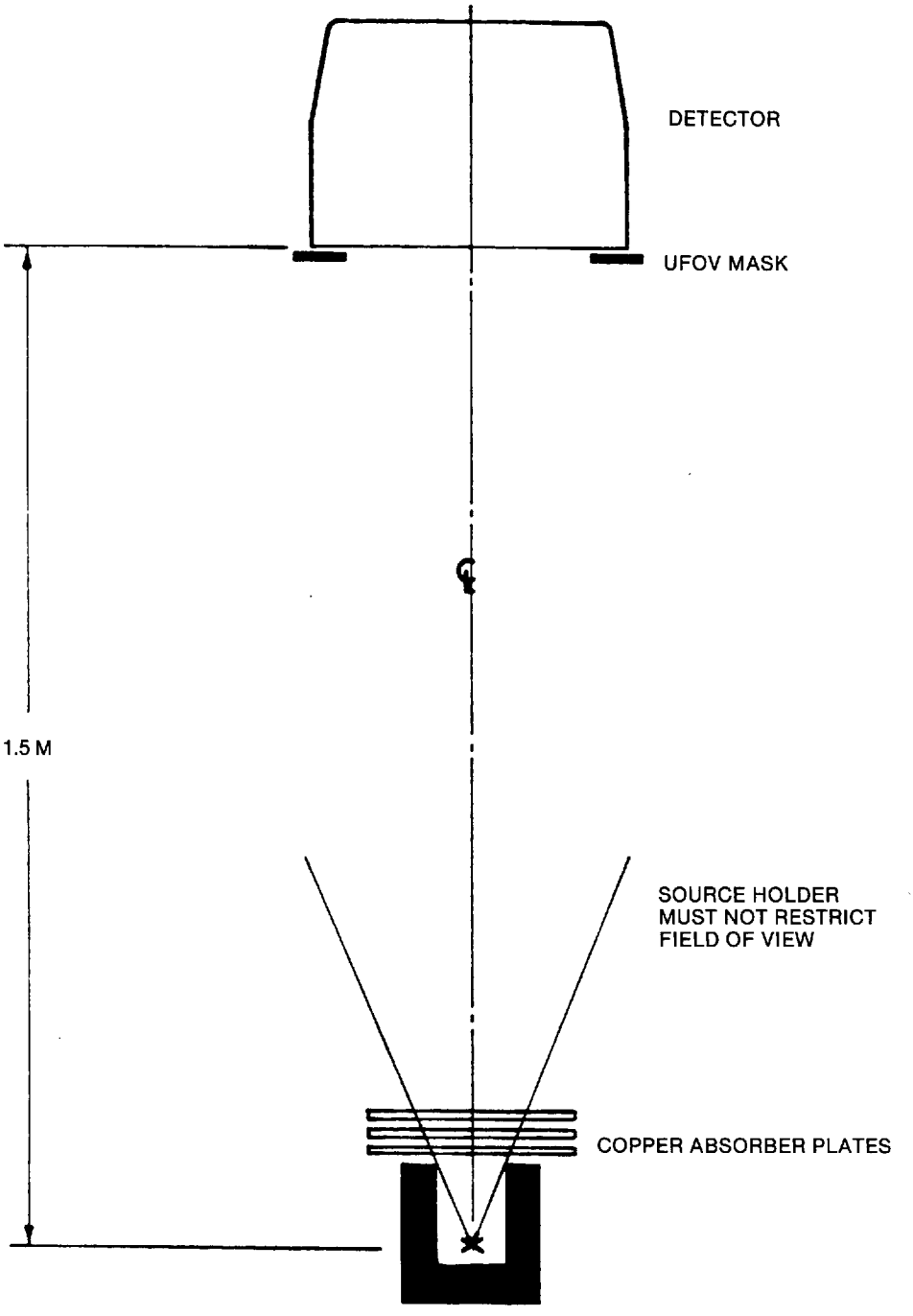


Fig. 2-2
GEOMETRY FOR COUNT RATE CURVE
(SINGLE CRYSTAL SCINTILLATION CAMERA)

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(5) A source holder for the ^{67}Ga source for the multiple window spatial registration tests.
(6) Capillary tubes for the system spatial resolution tests.
(7) Lucite™ scattering material.
(8) Dose calibrator.
(9) A 100-millimeter-diameter plastic Petri dish.

NEMA Standard 1-17-1980.

TESTS

NU 1-2.30 INTRINSIC SPATIAL RESOLUTION

Intrinsic spatial resolution 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 measured in millimeters.

A. Radionuclide

The radionuclide shall be ^{99m}Tc. Any other radionuclide(s) employed shall be separately reported. The analyzer window shall be 20 percent.

B. Count Rate

The count rate shall not exceed 10000 cps through a 20-percent window. Measurements performed at any higher count rate shall be separately reported.

C. 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 slits on 30-millimeter centers which are chords of the UFOV. The central slit lies along the diameter perpendicular to the axis of measurement and must be aligned to within plus or minus 1 millimeter at the edge of the field. The thickness of the mask shall be 3 millimeters for ^{99m}Tc. Refer to Fig. 2-1.

The radionuclide shall be a point source centered at least 5 UFOV diameters above the test pattern.

D. Digitization Resolution Perpendicular to Slits

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

E. Digitization Resolution Parallel to Slits

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

F. Spread Function Measurement

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

G. Half Maximum and Tenth Maximum Locations

The half maximum and tenth maximum locations shall be determined by linear interpolation from the nearest two neighboring pixels respectively, using the largest pixel value in each line spread function curve as the maximum. Refer to Fig. 2-3.

H. 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.

I. FWHM and FWTM Values

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

J. 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.

K. 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.

NEMA Standard 1-17-1980.

NU 1-2.31 INTRINSIC ENERGY RESOLUTION

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.

A. Radionuclide

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

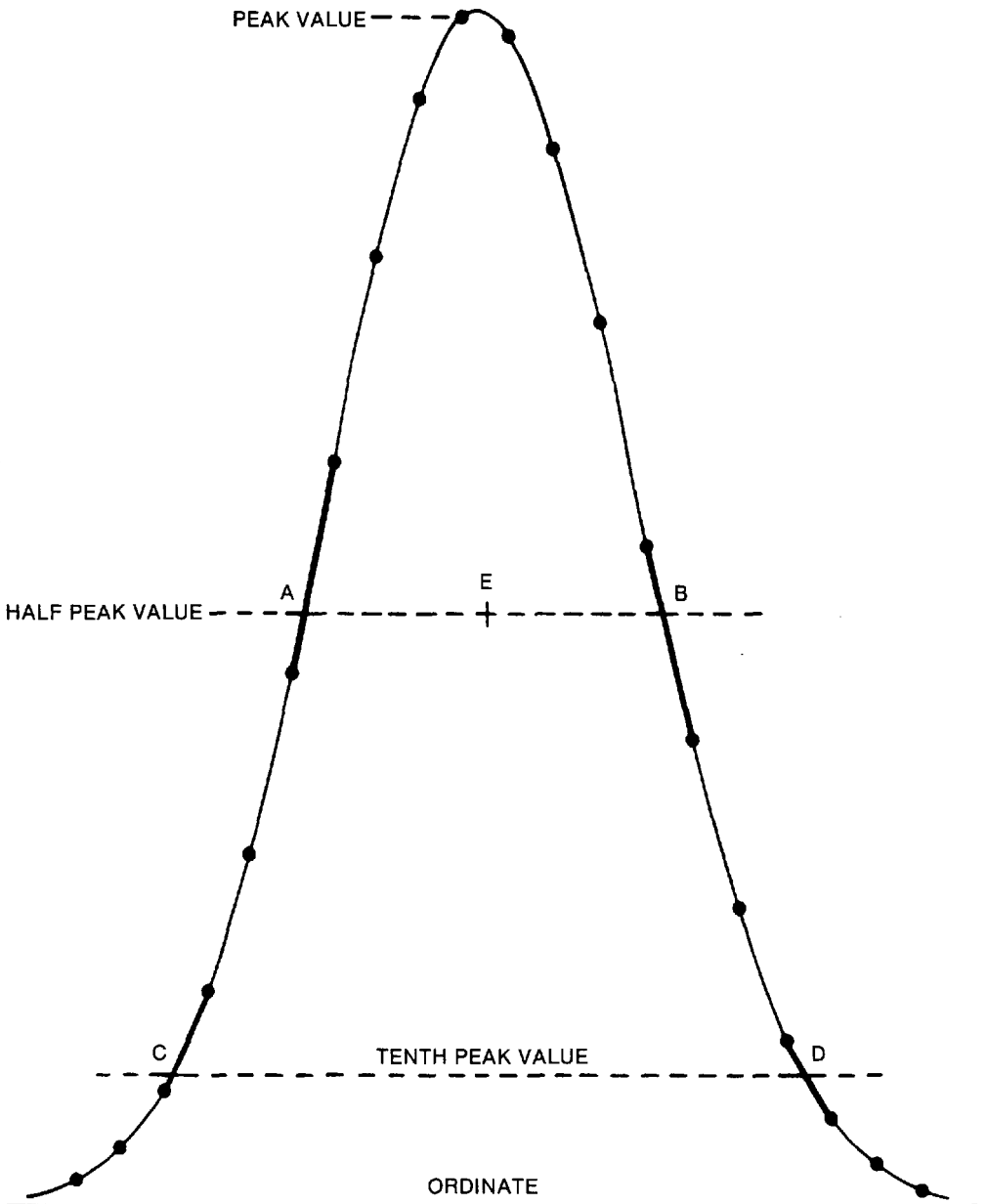
B. Source

The source shall be a point source at a minimum distance of 5 UFOV diameters above the uncollimated detector. The detector shall be masked with a 3-millimeter-thick lead ring to establish UFOV.

C. Count Rate

The integral count rate shall not exceed 20000 cps. Measurements performed at any higher count rates shall be separately reported.

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

B – A = FWHM in channels

D – C = FWTM in channels

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

Fig. 2-3
LINEAR INTERPOLATION OF HALF MAXIMUM, TENTH MAXIMUM AND CENTER LOCATION FOR SPATIAL RESOLUTION AND ENERGY RESOLUTION

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D. Stored Spectra

All spectra shall be stored to at least 10000 counts in the peak channel with a digitization resolution less than or equal to 0.02 FWHM.

E. Calibration of Measurement Instrument

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

(1) ***Establishment of keV per Channel Calibration Factor***—Storing individual spectra for ^{57}Co and ^{99m}Tc, 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 Fig. 2-3.

(2) ***Intrinsic Energy Resolution***—Utilizing the ^{99m}Tc 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.

NEMA Standard 1-17-1980.

NU 1-2.32 INTRINSIC FLOOD FIELD UNIFORMITY

Intrinsic flood field uniformity shall be expressed as "integral uniformity" (a maximum deviation) and a "differential uniformity" (a maximum rate of change over a specified distance, roughly slope). Both shall be measured for the UFOV (see par. E below) and the CFOV and expressed as plus or minus percentage values. In addition, as a class standard, point source sensitivity variations shall be expressed as plus or minus percentage variation.

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

Refer to Fig. 2-4 for a representation of the flood field geometry.

A. Radionuclide

The radionuclide employed shall be ^{99m}Tc. Any other radionuclide(s) employed shall be separately reported. The analyzer window shall be 20 percent.

B. Masking of Detector

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

C. Count Rate

The total count rate shall not exceed 30000 cps through a 20 percent window. Any variations in count rate or window width shall be separately reported.

D. Flood Field Image

The flood field image shall be stored in a 64×64 matrix. The measurement system gains shall be adjusted so that diameters of the flood field image are at least 60 pixels.

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

The 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

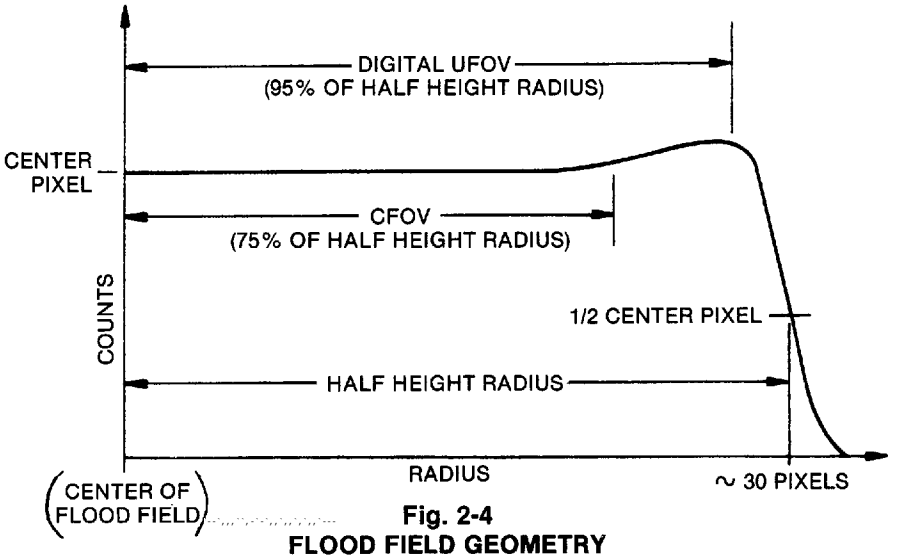


Fig. 2-4
FLOOD FIELD GEOMETRY

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E. Calculation of Center and Half-height Radius of Flood Field

The center of the flood field and the half-height radius of the flood field shall be calculated by locating the half-height points (points with a value of one-half the value of the center pixel) in each row and column by linear interpolation to nearest neighboring points surrounding the half height.

For this calculation, the UFOV shall be redefined as a circle centered on the flood field with a radius that is 95 percent of the half-height radius.

Similarly, the CFOV shall be redefined as a centered circle with a radius that is 75 percent of the half-height radius.

F. Integral Uniformity

For points within the area at interest (UFOV or CFOV) the maximum and the minimum values are identified, and their values are subtracted. This "span" is divided by the sum of the values at these two points, multiplied by 100, and expressed as a plus or minus percentage integral uniformity. The formula for integral uniformity shall be as follows:

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

G. Differential Uniformity

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

The flood is treated as a number of rows and columns (slices). The number of slices for the UFOV in both X and Y directions is approximately $2 \times 60 \times 0.95$ and for the CFOV is approximately $2 \times 60 \times 0.75$.

Each slice is processed by starting at one end, examining for 5 pixels from the start pixel and recording the maximum difference. The start pixel is moved forward 1 pixel and the next 5 pixels are examined, etc. For each slice, a largest deviation is found and for the whole set of slices (for the UFOV or CFOV), a 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 and expressed as a plus or minus percentage differential uniformity for the CFOV and UFOV.

$$\text{Differential uniformity} = \pm 100 \left(\frac{\text{Largest slice deviation (Hi} - \text{Low)}}{\text{Hi} + \text{Low}} \right)$$

H. Point Source Sensitivity

As a class standard, point source sensitivity shall be measured with a collimated point source of ^{99m}Tc at each point of a matrix centered in the UFOV with the space between points on each axis to be 30 millimeters. Typically there will be approximately 50 points for a 10-inch diameter camera and 125 points for a 15-inch diameter camera.

I. Source

The ^{99m}Tc 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.

J. Analyzer Window

The analyzer window shall be 20 percent. The count rate shall not exceed 10000 cps.

K. 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 100000 counts for any point in the matrix.

L. Decay of Radionuclide

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

M. Sensitivity Variation

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

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

NEMA Standard 1-17-1980.

NU 1-2.33 INTRINSIC SPATIAL LINEARITY

Intrinsic spatial differential linearity and absolute spatial linearity in both X and Y directions shall be measured. 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 test pattern. Absolute linearity shall be measured from the same test pattern data and shall be expressed as the maximum amount of spatial displacement measured in the CFOV and UFOV.

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A. Radionuclide

The radionuclide shall be ^{99m}Tc. Any other radionuclide(s) employed shall be separately reported. The analyzer window shall be 20 percent.

B. Count Rate

The count rate shall not exceed 10000 cps through a 20 percent window. Measurements performed at any higher count rate shall be separately reported.

C. Test Pattern

The test pattern shall consist of a lead mask covering the entire field of view with slits 1 millimeter in width on 30-millimeter centers which are chords of the UFOV. The central slit lies along the diameter perpendicular to the axis of measurement. The thickness of the mask shall be 3 millimeters for ^{99m}Tc. Refer to Fig. 2-1. This is the same test pattern that is employed in the intrinsic spatial resolution measurement.

D. Point Source

The radionuclide shall be a point source centered at least 5 UFOV diameters above the test pattern.

E. Digitization Resolution Perpendicular to Slits

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

F. Digitization Resolution Parallel to Slits

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

G. Line Spread Function Measurement

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

H. 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.

I. Differential Linearity Values

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

J. Absolute Linearity

Absolute linearity shall be determined by establishing an ideal grid from the measured data and determining the maximum displacement from this ideal grid.

Absolute linearity shall be reported by two values. One value each for the largest 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.

NEMA Standard 1-17-1980.

NU 1-2.34 INTRINSIC COUNT RATE PERFORMANCE

Five parameters shall be measured and reported: input count rate for a 20 percent count loss, maximum count rate; and as class standards, typical incident versus observed count rate curve, intrinsic spatial resolution at 75000 cps (observed), and intrinsic flood field uniformity at 75000 cps (observed).

A. Radionuclide

The radionuclide employed shall be ^{99m}Tc. Any other radionuclide(s) employed shall be separately reported. The analyzer window shall be 20 percent. Peaking shall be performed at at low count rate and shall not be manually readjusted during the test.

B. 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 rate) to $R_{-20\%}$ (the 20-percent count loss count rate) and thus shall be calculated in accordance with the following formula:

$$R_{obs} = Re^{-R\tau}$$

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

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

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

$$R_{-20\%} = \frac{1}{\tau} \ln\left(\frac{10}{8}\right) = \frac{0.2231}{\tau}$$

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(3) ***Acquisition of Data***—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 with activity within plus or minus 10 percent of the first 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 ^{99m}Tc and other short lived sources, repeat the procedure backwards and average the count rate values. The count rate for both sources present, R_{12}, must approximate the anticipated 20 percent loss count rate, within plus or minus 20 percent.

(4) ***Reported Value***—Report the input count rate for 20 percent loss.

C. 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 ^{99m}Tc source, and the maximum observed count rate shall be recorded. Care must be taken to minimize scatter.

D. Measurement of Typical Incident Versus Observed Count Rate Curve

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

(1) ***Copper Absorber Plates***—A number of copper absorber plates of equal thickness, individually calibrated for attenuation of ^{99m}Tc 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 ^{99m}Tc 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 required 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 incident count rate can be obtained by removal of a calculated number of absorber plates.

(5) ***Foldover in Observed Count Rate Curve***—At least eight data points shall be measured between zero incident count rate and that incident count rate required to produce foldover in the observed count rate curve.

(6) ***Typical Count Rate***—The incident rate versus observed rate points shall be graphed, curve fitted, and labeled as typical count rate.

E. Intrinsic Spatial Resolution Measurements

The intrinsic spatial resolution measurements of par. NU 1-2.30 shall be performed for the UFOV only, at an observed count rate of 75000 cps through a 20 percent window and reported as class standard values.

F. Intrinsic Flood Field Uniformity Measurements

The intrinsic flood field uniformity measurements of par. NU 1-2.32 shall be performed at an observed count rate of 75000 cps through a 20 percent window and reported as class standard values.

NEMA Standard 1-17-1980.

NU 1-2.35 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.

A. Radionuclide

The radionuclide to be employed shall be ^{67}Ga. 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.

B. Total Count Rate

The total count rate shall not exceed 10000 cps through each window. Each window shall be set to 20 percent.

C. Computation of ^{67}Ga Source Displacement

A ^{67}Ga 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 two or three windows, and the displacement in millimeters computed.

D. X-Axis Displacement Measurement

(1) ***Digitization Resolution***—For the X-axis displacement measurement, the digitization

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resolution shall be less than or equal to 0.1 FWHM (see par. NU 1-2.30.D) in the X-axis. Y-axis resolution is irrelevant.

(2) ***Peak Channel Count***—The collimated source shall be placed on the +X axis, 75 percent of the distance from the center of the UFOV circle (on the CFOV line). Through each window, independently, at least 10000 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 par. NU 1-2.30.G. 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, 75 percent of the distance from the center to the UFOV circle. 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 two (or four) X-displacement values in millimeters shall be recorded as the maximum X registration error, in millimeters.

E. Y-Axis Displacement

The Y-axis displacement values are measured by following the procedure in par. NU 1-2.35.D above and substituting Y axis and X axis. The maximum Y registration error in millimeters is recorded.

F. Reporting of Displacement Factor

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

NEMA Standard 1-17-1980.

NU 1-2.36 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 expressed in millimeters, with the collimator specified.

A. Radionuclide

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

B. Count Rate

The count rate shall not exceed 10000 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.

C. Source

(1) ***Composition of Sources***—The sources shall consist of two capillary tubes, each having an inside diameter less than or equal to 1.0 millimeter, and a length of approximately the diameter 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 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 Lucite™ shall be interposed between the capillary tube(s) and the collimator, and 50 millimeters of Lucite™ shall be placed behind the capillary tube(s). The Lucite™ is permitted to be assembled from thinner pieces but must cover the entire UFOV.

D. 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 plus or minus 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) ***Digitization Resolution***—The digitization resolution perpendicular to the tube(s) shall be less than 0.1 FWHM.

The digitization resolution parallel to the tube(s) shall be no greater than 30 millimeters.

(4) ***Peak Point Counts***—At least 10000 counts shall be collected in the peak point of each line spread function.

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(5) ***Calculation and Calibration Measurements of FWHM and FWTM***—Per the procedure in par. NU 1-2.30.G, 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 averaged for the X and Y axes. The use of scattering material per step (4) of par. NU 1-2.36.C shall be clearly indicated.

E. Calculation of System Spatial Resolution Based Upon an Initial System Resolution Measurement

System spatial resolution may be reported as a calculated value based on an initial system resolution measurement.

(1) ***Collimator Resolution***—From a system spatial resolution measurement of par. NU 1-2.36 and an intrinsic spatial resolution over the CFOV of par. NU 1-2.30.K, collimator resolution is calculated from:

$$R_s = [R_c^2 + (R_i/M)^2]^{1/2}$$

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 aperture-to-detector distance divided by object-to-aperture distance. For diverging collimators (M less than 1) and converging collimators (M greater than 1), M is the ratio of image size to object size for the object at a given depth (100 millimeters nominal).

(2) ***Calculation of System Spatial Resolution for Changed Intrinsic Resolution***—Knowing collimator resolution, system spatial resolution values for changed intrinsic resolution may be calculated and reported in accordance with the equation given in step (1) above.

Authorized Engineering Information 1-17-1980.

NU 1-2.37 SYSTEM SENSITIVITY

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

A. Radionuclides

The radionuclides employed for these measurements shall be as follows:

Collimator Energy	Radionuclide
140 keV	^{99m}Tc
280 keV	^{203}Hg
360/400 keV	^{131}I

Deviations from these sources shall be reported separately.

B. Count Rates

The count rate shall not exceed 10000 cps through a 20 percent window. Measurement performed at any higher count rate shall be separately reported.

C. 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 shall be subtracted from the original reading to obtain the amount of activity in the dish. (Calibration methods are set forth in the NRC Regulatory Guide 10.8, January, 1979, *Guide for the Preparation of Applications for Medical Programs,* Appendix D, Section 2, "Methods for Calibration for Dose Calibrator," or the latest revision thereof.)

Counts/(minute • μCi) 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.

NEMA Standard 1-17-1980.

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.

Authorized Engineering Information 1-17-1980.

* Refer to Appendix C for additional information about referenced publications.

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Part 3
MULTIPLE CRYSTAL SCINTILLATION CAMERA TEST METHODS

DEFINITIONS

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

NU 1-3.01 USEFUL FIELD OF VIEW (UFOV)

Unless otherwise specified, the useful field of view (UFOV) is the largest area bounded by the collimated field of view, defined at the outward surface of the collimator.

NEMA Standard 1-17-1980.

NU 1-3.02 DETECTOR FIELD OF VIEW (DFOV)

The detector field of view (DFOV) is defined as the area of the detector array and is equal to the UFOV when a parallel hole collimator is used.

NEMA Standard 1-17-1980.

GENERAL

NU 1-3.10 REPORTED VALUES

In stating specifications, all reported values shall be labeled as "worst case," "better than," "not to exceed"; DFOV, UFOV, and the collimator specified.

NEMA Standard 1-17-1980.

NU 1-3.11 ADDITIONAL TESTS

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

NEMA Standard 1-17-1980.

NU1-3.12 TRACEABILITY

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

NEMA Standard 1-17-1980.

TEST EQUIPMENT

NU 1-3.20 TEST EQUIPMENT PERFORMANCE

All tests shall be performed utilizing the data processing capabilities of the multiple detector imaging device. Measurements of field uniformity and energy resolution or linearity correction, or both energy resolution and linearity correction, shall be specified as intrinsic or system corrected.

NEMA Standard 1-17-1980.

NU 1-3.21 MINIMUM TEST EQUIPMENT REQUIREMENTS

The following test equipment shall be required.

(1) Slit mask as shown in Fig. 3-1.
(2) ^{99m}Tc point source.
(3) ^{99m}Tc flood source (same area as UFOV).
(4) ^{99m}capillary tube sources (two each).
(5) Lucite™ scattering material, 100 and 50 millimeters thick (same area as UFOV).
(6) Dose calibrator traceable to an NBS source.

NEMA Standard 1-17-1980.

TESTS

NU 1-3.30 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 par. NU 1-3.36.

NEMA Standard 1-17-1980.

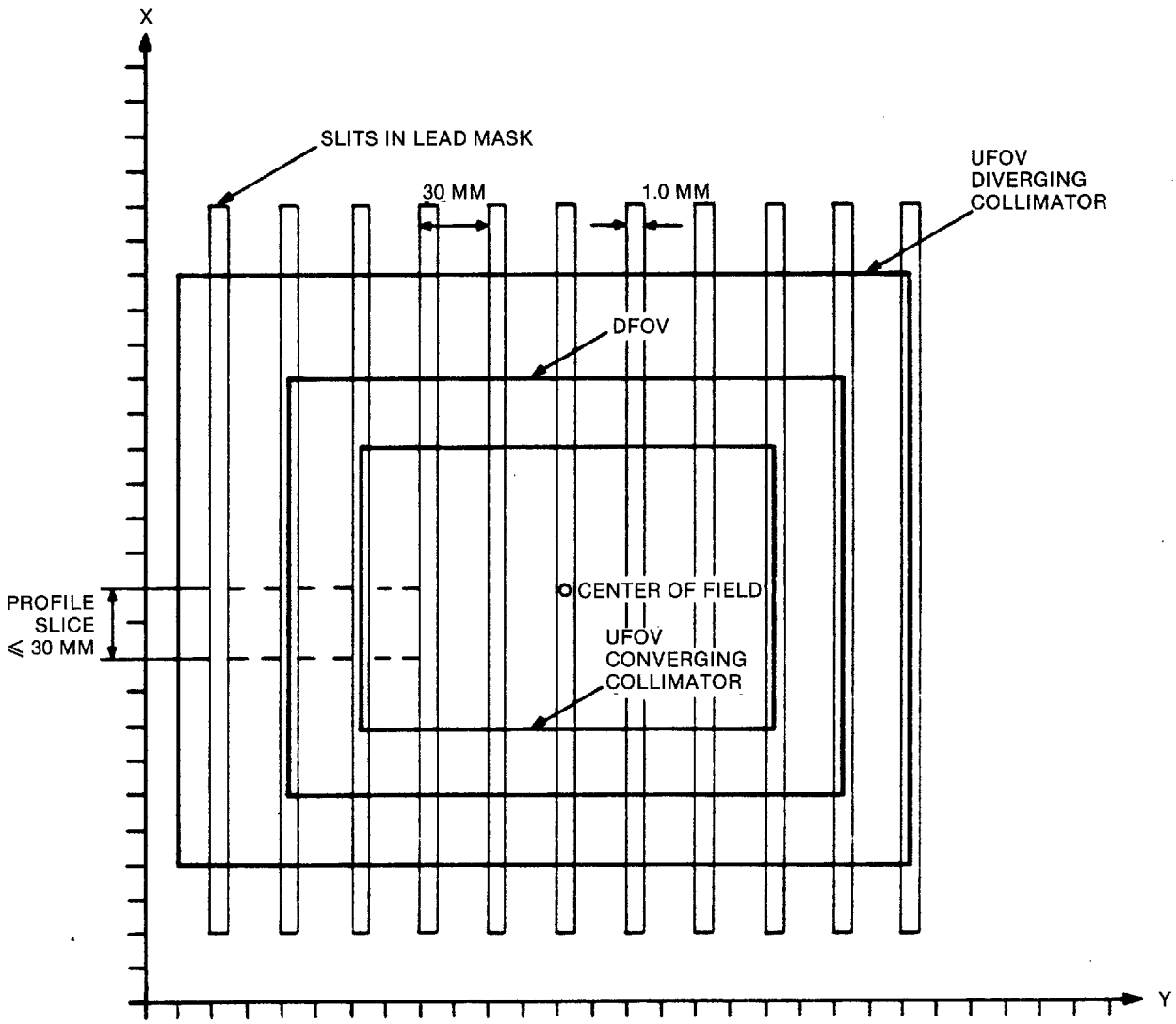
NU 1-3.31 INTRINSIC ENERGY RESOLUTION

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.

A. Radionuclide

^{99m}Tc energy resolution shall be reported over the DFOV.

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DIGITIZE TO NORMAL STATIC MULTIPOSITION RESOLUTION
CHANNEL WIDTH IN BOTH X AND Y AXES

Fig. 3-1
LINEARITY PHANTOM

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B. Source

The source shall be a point source placed directly above the center of the DFOV at a minimum distance equivalent to 5 times the long axis of the DFOV. No collimator shall be used.

C. Count Rate

The integral count rate shall not exceed 20000 cps. Measurement performed at any higher count rates shall be separately reported.

D. Stored Spectra

All spectra shall be stored to at least 10000 counts in the peak channel with digitization resolution as specified in par. NU 1-3.31.E, below.

E. Calibration of Energy Spectrum

The measurement shall be performed by utilizing the spectrometer of the multiple detector imaging device with the window set at 1 percent and with the bias specified at the minimum level permissible above system noise. The lower level shall be advanced repetitively in 1-percent steps with dwell times sufficiently long to acquire the counts as specified in par. NU 1-3.31.D, above. The data acquisition system of the imaging device shall be run in the dynamic mode with each frame time equal to the dwell time of the lower level. The start of a new frame shall be synchronized with the change in lower level. A second radionuclide, ^{109}Cd, shall be employed to calibrate the energy spectrum.

(1) ***keV Per Frame Calibration Factor***—Storing individual spectra for ^{109}Cd and ^{99m}Tc, the difference in frame numbers for the peak centers, determined from the linearly interpolated half height frame numbers of each photopeak, shall be divided into the difference in photopeak energies (140.5 keV – 88 keV = 52.5 keV) to arrive at a keV per frame calibration factor. Refer to Fig. 2-3.

(2) ***Intrinsic Energy Resolution***—Utilizing the ^{99m}Tc spectrum stored in accordance with step (1) above, the FWHM shall be calculated in frames by linear interpolation between the frame 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.

NU 1-3.32 SYSTEM FLOOD FIELD UNIFORMITY

System flood field uniformity shall be expressed as plus or minus percentages for:

(1) Integral uniformity (maximum deviation).
(2) Differential uniformity (maximum rate of change over a specified distance).
(3) Average uniformity (average deviation) over the UFOV.

The data shall be acquired from a ^{99m}Tc flood source counted to a maximum specified count (N max) in the highest detector. The N max shall be no less than 9000. The flood field image shall be stored in a matrix having as many elements as there are detectors. The field uniformity correction feature inherent in the multicrystal camera shall be used.

A. Radionuclide and Collimator

The radionuclide employed shall be ^{99m}Tc 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 conditions shall be those normally utilized for ^{99m}Tc and shall be specified.

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

B. Count Rate

The total count rate shall not exceed 30000 cps through the specified analyzer settings. Any variations in count rate or analyzer settings shall be separately reported.

C. Flood Field Image

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

D. Integral Uniformity

Integral uniformity shall be obtained as follows: the maximum value and the minimum value shall be identified, and their magnitudes shall be subtracted. This span is divided by the sum of the two values, multiplied by 100, and expressed as a percentage integral uniformity. The formula for integral uniformity shall be as follows:

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

E. Differential Uniformity

Differential uniformity shall be the measurement of the worst case rate of change of the flood field over a limited distance. For each row and column of the flood image, the maxi-

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mum and minimum values shall be identified, and their magnitudes shall be subtracted to form the largest deviation. The largest deviation among all the rows and columns shall be found and divided by the sum of the values for the two points representing the largest deviation, multiplied by 100, and expressed as a percentage differential uniformity. The formula for differential uniformity shall be as follows:

Differential uniformity =

$$100\left(\frac{\text{Largest row or column deviation (Hi} - \text{Low)}}{\text{Hi} + \text{Low}}\right)$$

F. Average Uniformity

Average uniformity shall be calculated as the percentage ratio of the total array counts to the theoretical maximum array counts, M × N max (where M is the total number of detectors).

NEMA Standard 1-17-1980.

NU 1-3.33 SYSTEM SPATIAL LINEARITY

Spatial linearity in both X and Y directions shall be measured for the specific UFOV and collimator employed. Spatial differential linearity and absolute spatial linearity in both X and Y directions shall be measured. Differential linearity shall be expressed as millimeters of standard deviation of line spread function peak separations using the spatial resolution test pattern with slits on 30-millimeter centers. Absolute linearity shall be measured from the same test pattern data and shall be expressed as the maximum amount of spatial displacement measured in the UFOV.

A. Radionuclide

The radionuclide shall be ^{99m}Tc. Any other radionuclides employed shall be separately reported. The analyzer window shall be that normally employed for ^{99m}Tc and shall be specified.

B. Count Rate

The count rate shall not exceed 10000 cps through the window specified in par. NU 1-3.33.A, above. Measurements performed at any higher count rate shall be separately reported.

C. Test Pattern

The test pattern shall consist of a lead mask covering the entire field of view with slits 1 millimeter in width on 30-millimeter centers. The central slit shall lie parallel to a line of detectors perpendicular to the axis of measurement. The thickness of the mask shall be 3 millimeters for ^{99m}Tc. Refer to Fig. 3-1.

D. Flood Source

The radionuclide shall be a flood source in contact with the mask.

E. Spatial Digitization Resolution

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

F. Digitization Resolution Parallel to Slits

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

G. Line Spread Function Measurement

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

H. 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.

I. Differential Linearity Values

Two values shall be reported for differential linearity, one for the X measurements in the UFOV and one for the Y measurements in the UFOV. Each value shall consist of the standard deviation in millimeters of adjacent peak separations of all peaks in the specified field of view. The profile slice in each case shall be taken through the edge of the field.

J. Absolute Linearity

Absolute linearity shall be reported as one value (the larger of X or Y) for the absolute linearity in the UFOV. The profile slice shall be taken at the edge of the field. The center slit shall lie along a line of detectors perpendicular to the axis of measurement and aligned to within plus or minus 1 millimeter at the edge of the UFOV. This defines a grid of points: the reported values shall be the maximum amount of spatial displacement in millimeters from these points.

NEMA Standard 1-17-1980.

NU 1-3.34 INTRINSIC COUNT RATE PERFORMANCE

Five parameters shall be measured and reported: input count rate for a 20-percent count loss, maximum count rate; and as class standards, typical incident versus observed count

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rate curve, system spatial resolution at 75000 cps (observed) and intrinsic flood field uniformity at 75000 cps (observed) through the normal specified spectrometer settings for ^{99m}Tc radionuclide.

The analyzer settings shall be those normally employed for ^{99m}Tc and shall be specified.

A. Twenty-percent Count Rate Loss

The 20-percent count rate loss 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 shall be calculated in accordance with the following formula:

$$R_{obs} = Re^{-R\tau}$$

(1) ***Radionuclide***—The radionuclide employed shall be ^{99m}Tc. Any other radionuclide employed shall be reported separately.

(2) ***Dead Time***—The dead time τ shall be calculated according to a modified two-source measurement and reduced according to the formula:

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

(3) ***Input Count Rate***—The input count rate for a 20 percent loss ($R_{-20\%}$) shall then be calculated from:

$$R_{-20\%} = \frac{1}{\tau} \ln\left(\frac{10}{8}\right) = \frac{0.2231}{\tau}$$

(4) ***Acquisition of Data***—The data shall be acquired by removing all collimators from the camera and exposing the DFOV to a source suspended near its 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 with activity within plus or minus 10 percent of the first in such a fashion that neither source obscures the other's view of the DFOV. Record R_{12}. Remove the first source and record R_2. For ^{99m}Tc 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 plus or minus 20 percent.

(5) ***Reported Value***—Report the input count rate for 20-percent loss.

B. Maximum Count Rate

The maximum count rate shall be determined by using normal spectrometer settings (which shall be specified) for ^{99m}Tc radionuclide. The camera shall be slowly approached with about a 2 to 3 mCi ^{99m}Tc source centered over the DFOV and the maximum observed count rate shall be recorded. Care must be taken to minimize scatter.

C. Measurement of Typical Incident Versus Observed Count Rate Curve

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

(1) ***Copper Absorber Plates***—A number of equal thickness copper absorber plates individually calibrated for attenuation (approximately 2.5 millimeters thick) shall be placed between the source, in close proximity to the source, and the detector masked to the DFOV.

(2) ***Source***—The source shall be a ^{99m}Tc 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 2500 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 a calculated number of absorber plates.

(5) ***Foldover in Observed Count Rate Curve***—At least 8 data points shall be measured between zero incident count rate and that incident count rate required to produce foldover in the observed count rate curve.

(6) ***Typical Count Rate***—The incident rate versus observed rate points shall be graphed, curve fitted and labeled as typical count rate.

D. System Spatial Resolution Measurements

The system spatial resolution measurements of par. NU 1-3.36 shall be performed for the UFOV only at an observed count rate of 75000 cps through the normal specified spectrometer settings and reported as class standard values.

E. Intrinsic Flood Field Uniformity Measurements

The intrinsic flood field uniformity measurements of par. NU 1-3.32 shall be performed at

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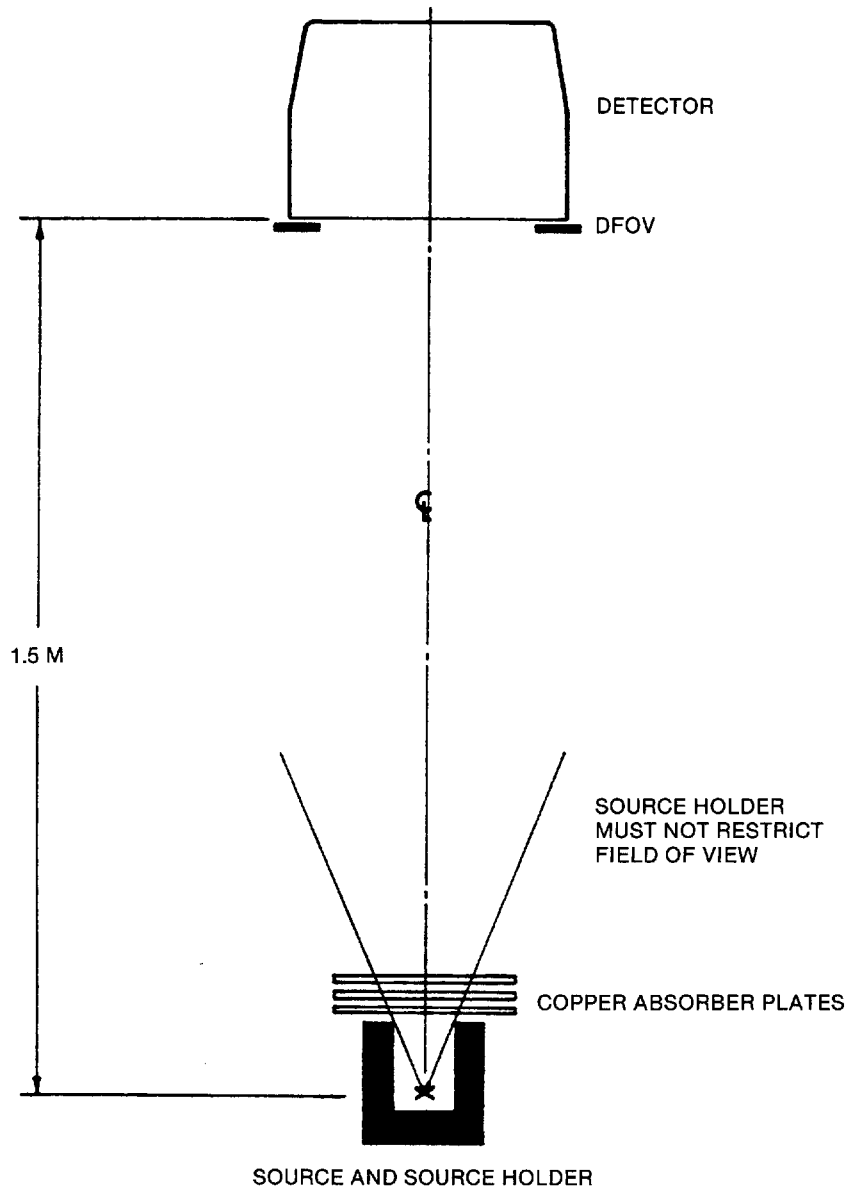


Fig. 3-2
GEOMETRY FOR COUNT RATE CURVE
(MULTIPLE CRYSTAL SCINTILLATION CAMERA)

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an observed count rate of 75000 cps through the normal specified spectrometer settings and reported as class standard values.

NEMA Standard 1-17-1980.

NU 1-3.35 MULTIPLE WINDOW SPATIAL REGISTRATION

The concept of multiple window spatial misregistration is not a possible problem with a multicrystal gamma camera; therefore, performance standards are not applicable or relevant.

Authorized Engineering Information 1-17-1980.

NU 1-3.36 SYSTEM SPATIAL RESOLUTION WITH AND WITHOUT SCATTER

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

A. Radionuclide

The radionuclide to be employed for this measurement shall be ^{99m}Tc. Any other radionuclides employed for higher energy collimators shall be separately reported.

B. Count Rate

The count rate shall not exceed 10000 cps through the specified spectrometer settings employed for ^{99m}Tc. Measurements performed at any higher count rate shall be separately reported.

C. Sources

(1) ***Composition of Sources***—The sources shall consist of two capillary tubes, each having an inside diameter less than or equal to 1.0 millimeters and a length of 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 Lucite™ shall be interposed between the capillary tubes and the collimator, and 50 millimeters of Lucite™ shall be placed behind the capillary tubes. The Lucite™ is permitted to be assembled from thinner pieces but must cover the entire UFOV.

D. Measurement of FWHM and FWTM Axes

(1) ***Method***—The measurement of each axis of FWHM and FWTM shall be performed with a single capillary tube lying parallel to the axis of measurement.

(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) ***Digitization Resolution***—The digitization resolution of the system perpendicular to the tube shall be that normally employed in static imaging utilizing scanning capabilities of the imaging device. Profile slices along the tubes shall be no greater than 30 millimeters.

(4) ***Peak Point Counts***—At least 10000 counts shall be collected in the peak point of each line spread function.

(5) ***Calculation and Calibration Measurements 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 step (4) of par. NU 1-3.36.C, above, shall be clearly indicated.

NEMA Standard 1-17-1980.

NU 1-3.37 SYSTEM SENSITIVITY

As a class standard, the system sensitivity (camera and collimator) shall be measured for each collimator and reported in counts/(minute • μCi) of the measured radionuclide for the window normally employed which shall be specified.

A. Radionuclides

The radionuclides employed for these measurements shall be as follows:

Collimator Energy	Radionuclide
140 keV	^{99m}Tc
280 keV	^{203}Hg
360/400 keV	^{131}I

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Deviations from these sources shall be reported separately.

B. Count Rates

The count rate shall not exceed 10000 cps through the window normally employed which shall be specified. Measurement performed at any higher count rate shall be separately reported.

C. 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 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 are set forth in the NRC Regulatory Guide 10.8, January, 1979, *Guide for the Preparation of Applications for Medical Programs*, Appendix D, Section 2, "Methods for Calibration for Dose Calibrator," or the latest revision thereof.)*

The counts/(minute • μCi) for the gamma ray of the radionuclide employed 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.

NEMA Standard 1-17-1980.

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.

Authorized Engineering Information 1-17-1980.

*Refer to Appendix C for additional information about referenced publications.

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Appendix A
RATIONALE FOR SINGLE CRYSTAL SCINTILLATION CAMERA TEST METHODS

(Approved as Authorized Engineering Information 1-17-1980.)

NU 1-A1.01 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 (1), above.
(3) Routine clinical quality control.

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

A. Traceability

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

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

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

NU 1-A1.02 RATIONALE FOR CHOSEN MEASUREMENT TECHNIQUES

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

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

A. General Standards and Definitions Rationale

(Refer to pars. NU 1-2.01 and NU 1-2.02.) 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 par. NU 1-2.10.) The use of "typical," "average," "in the range of" labeling on reported performance values is not in accordance with these standards. Exception is made in the case of par. NU 1-2.34.D, the input versus observed count rate curve.

B. Intrinsic Spatial Resolution Rationale

(1) ***Choice of 1-millimeter Slit Width***—(Refer to par. NU 1-2.30.C.) 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 will lead to an approximate 10 percent overestimation of FWHM for values of FWHM in the 2.5- to 3-millimeter range. But, by fixing the slit width at 1 millimeter the reported values will be comparable.

(2) ***0.1 FWHM Digitization Resolution***—(Refer to par. NU 1-2.30.D.) The digitization 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.

(3) ***Opposite Axis Digitization Resolution***—(Refer to par. NU 1-2.30.E.) The "opposite axis" digitization resolution less than or equal to 30 millimeters is necessary or nonlinearities and inevitable small rotations of the slit phantom will contribute errors to calculated FWHM and FWTM. This could also be achieved by masking the slit phantom in 30-millimeter segments.

(4) ***1000-Peak Channel Count***—(Refer to par. NU 1-2.30.F.) Collecting 1000 counts in the peak channel of each line spread function measurement does not give sufficient statistical validity for *local* measurement; but, since 50 to 100 measurements will be averaged for the reported results, the FWHM and FWTM values reported have the statistical validity of a 50000- to 100000-count line spread function measurement.

(5) ***Calculated Value at Center Slit***—(Refer to par. NU 1-2.30.H.(2).) Locating each calculated value at the center of each slit segment is necessary to allow selection of those slit segments lying within the CFOV.

C. Intrinsic Energy Resolution Rationale

(1) ***Use of keV Values***—(Refer to par. NU 1-2.31.) 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 par. NU 1-2.31.E.) Calibration using an alternate source is essential due to nonlinearities

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in NaI(Tl), nonlinearities in processing electronics, and zero channel errors in the ADC.

D. Intrinsic Flood Field Uniformity Rationale

(1) ***Differential Uniformity***—(Refer to par. NU 1-2.32.) Differential uniformity is specified in addition to the more conventional integral uniformity as a method to better depict nonuniformities of a higher spatial frequency. Specification of RMS deviation is not in accordance with these standards due to the potential for masking flood defects of a small physical extent.

(2) ***Effective Radius***—(Refer to par. NU 1-2.32.D.) The relative gains of the measurement system may not be equal, in which case, a gain calibration factor may have to be determined, from par. NU 1-2.32.E. The effective radius r_{xy} for a given location will therefore be given by:

$$r^2_{xy} = (X - X_{center})^2 + K^2(Y - Y_{center})^2$$

Where:

K is the ratio of X axis gain to Y axis gain.

(3) ***Counts Stored per Pixel***—(Refer to par. NU 1-2.32.D.) Storing 4000 counts per pixel leads to +1.58 percent statistics. Particularly for the integral uniformity measurement, it is probable that several pixels will deviate more than 3 standard deviations from the mean, or roughly plus or minus 5 percent, since approximately 3000 samples will be examined. Since, for uniformity corrected systems, the integral uniformity specification will be comparable to plus or minus 5 percent, the 9-point smooth is required, which will reduce statistical uncertainty by a factor of 2.

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

For this reason, storage in a 64 × 64 matrix is 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.

(4) ***Digital UFOV Definition***—(Refer to par. NU 1-2.32.E.) A digital UFOV is defined, which will be slightly smaller than the UFOV employed elsewhere. The redefinition is necessary for determining uniformity, since outside this limit, the edge of the field would generate very large integral and differential errors due to the UFOV mask.

(5) ***Search Range for Differential Uniformity***—(Refer to par. NU 1-2.32.G.) The range of search for differential uniformity was picked to be 6 channels. This corresponds to 6/60 = 10 percent of field diameter, which corresponds to the radius of a photomultiplier tube in a 37-tube camera.

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 which typically occur with one cycle per photomultiplier tube.

(6) ***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.

E. Intrinsic Spatial Linearity Rationale

(1) ***Intent of Measurement***—(Refer to pars. NU 1-2.33.I and NU 1-2.33.J.) The intent of this measurement technique was that the same set of measurements and calculations from pars. NU 1-2.30.C through NU 1-2.30.H for spatial resolution may be employed for spatial linearity calculations.

F. Intrinsic Count Rate Performance Rationale

(1) ***Count Rate***—(Refer to par. NU 1-2.34.) 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 75000 cps resolution and uniformity as class standards implies that these measurements will not be performed on every camera.

(2) ***20-Percent Count Loss Rate***—(Refer to par. NU 1-2.34.B.) 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 of Ralph Adams, Gerald J. Hine, C. Duane Zimmerman: Deadtime 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 par. NU 1-2.34.D.) The copper absorber technique for measurement of incident versus observed count rate was chosen over the decaying source method because it is far quicker to perform and therefore less subject to long-term drift errors.

Since copper sheet, less than or equal to 2.5 millimeters thick, is not readily available to plus or minus 1 percent thickness tolerance, it is essential to individually calibrate each copper absorber. Using the geometry of Fig. 2-2 and a sufficiently weak ^{99m}Tc source to

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produce less than or equal to 5000 cps, each absorber should be introduced and the ratio of count rates recorded.

NOTE: Since the half-value thickness for copper is approximately 3 millimeters for 140 keV photons, the absorbers must 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.

(4) ***High Count Rate Resolution and Uniformity***—(Refer to pars. NU 1-2.34.E and NU 1-2.34.F.) High count rate resolution and uniformity are specified at 75000 cps rather than a lower value. The higher count rate was chosen since at lower rates the performance of a modern scintillation camera is not degraded from low count rate performance by an amount that is statistically significant.

G. Multiple Window Spatial Registration Rationale

(1) ***Collimated ^{67}Ga Source***—(Refer to par. NU 1-2.35.) The collimated ^{67}Ga source was chosen rather than a bar or slit test pattern due to the impracticality of constructing a high energy test pattern.

(2) ***Avoidance of Positioning Errors***—(Refer to par. NU 1-2.35.D(2).) With the source in each location, it is important to acquire data sequentially through each window, then move the source to avoid positioning errors.

H. System Spatial Resolution Rationale

(1) ***Worst Case Intrinsic Resolution***—(Refer to par. NU 1-2.36.) 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 par. NU 1-2.36.D(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 par. NU 1-2.36.E.) Calculation of system spatial resolution, with and without scatter, for a changed intrinsic resolution is based on the validity of the expression:

$$R_s = \left[R_c^2 + (R_i/M)^2 + R^2_{scatt}\right]^{1/2}$$

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)
R_{scatt} = Scatterer resolution
Without scatter, $R_{scatt} = 0$

With scatter, the collimator resolution determined in step (1) of par. NU 1-2.36.E is actually:

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

In this manner, calculating new system spatial resolution values for changing intrinsic resolution is equally valid for the scatter and nonscatter situation.

I. System Sensitivity Rationale

(Refer to par. NU 1-2.37.C.) The calibration of the dose calibrator to a NBS traceable source is essential. The dose calibrator must be recalibrated for each radionuclide energy used.

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Appendix B
RATIONALE FOR MULTIPLE CRYSTAL SCINTILLATION CAMERA TEST METHODS

(Approved as Authorized Engineering Information 1-17-1980.)

NU 1-B1.01 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 document establishes standardized performance measurement and reporting techniques to satisfy the need set forth in step (1), above.

A. Traceability

The user must have some means to correlate the performance he observes to the numeric data measured on the device by the manufacturer. The use of data and images supplied will provide traceability via more simple and field reproducible techniques.

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

NU 1-B1.02 RATIONALE FOR CHOSEN MEASUREMENT TECHNIQUES

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

A. General Standards and Definitions Rationale

(Refer to pars. NU 1-3.01 and NU 1-3.10.) Measurements for UFOV are reported, since the use of converging and diverging collimators may produce distortions not in the field of a normal parallel hole collimator.

The use of "typical," "average," and "in the range of" labeling on reported performance values is not in accordance with these standards. Exception is made in the case of par. NU 1-3.34.C, the input versus observed count rate curve.

B. Intrinsic Energy Resolution Rationale

(1) ***Alternate Source Calibration***—(Refer to par. NU 1-3.31.E.) Calibration using an alternate source is essential due to nonlinearities in NaI(Tl),

C. Flood Field Uniformity Rationale

(1) ***Differential Uniformity***—(Refer to par. NU 1-3.32.) Differential uniformity is specified in addition to the more conventional integral uniformity so as to depict nonuniformities of a higher spatial frequency.

D. Spatial Linearity Rationale

(Refer to par. NU 1-3.33.A.) While specifications will be quoted at ^{99m}Tc, the manufacturer should establish traceability between that specification and spatial linearity for the radionuclide employed in testing.

E. Intrinsic Count Rate Performance Rationale

(1) ***Count Rate***—(Refer to par. NU 1-3.34.) 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 75000 cps resolution and uniformity as class standards imply that these measurements will not be performed on every camera.

(2) ***20-Percent Count Loss Rate***—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 set forth in Ralph Adams, Gerald J. Hine, and C. Duane Zimmerman: Deadtime 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 par. NU 1-3.34.C.) The copper absorber technique for measurement of incident 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.

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Since copper sheet, less than or equal to 2.5 millimeters thick, is not readily available to plus or minus 1 percent thickness tolerance, it is essential to individually calibrate each copper absorber. Using the geometry of Fig. 3-2 and a sufficiently weak ^{99m}Tc source to produce less than or equal to 5000 cps, each absorber should be introduced and the ratio of count rates recorded.

NOTE: Since the half-value thickness for copper is approximately 3 millimeters for 140-keV photons, the absorbers must 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.

(4) ***High Count Resolution and Uniformity***—(Refer to pars. Nu 1-3.34.D and NU 1-3.34.E.) High count rate resolution and uniformity are specified at 75000 cps rather than a lower value. The higher count rate was chosen since, at lower rates the performance of a modern scintillation camera is not degraded from low count rate performance by an amount that is statistically significant.

F. System Spatial Resolution Rationale

(1) ***Single Capillary Tube Measurement for FWHM and FWTM***—(Refer to step (1) of par. NU 1-3.36.D.) 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.

G. System Sensitivity Rationale

(Refer to par. NU 1-3.37.B.) The calibration of the dose calibrator to a NBS traceable source is essential. The dose calibrator must be recalibrated for each radionuclide energy used.

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Appendix C
REFERENCED STANDARDS

Provided below is the title and publication number of the standard referenced, in part or in full, in this standards publication. The mailing address of the referenced organization is also provided.

Nuclear Regulatory Commission
1717 H Street, N.W.
Washington, D.C. 20037

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

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NEMA STANDARDIZATION

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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.

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