Gamma Camera Acceptance Testing: The First Quality Control

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Objective: When a gamma camera is delivered, it should be evaluated to verify that it meets the performance level promised by the specifications.
Methods: We explain the protocol we used for evaluating camera performance as an acceptance test for a newly installed system using the principles of the National Electrical Manufacturers Association guidelines.
Results: Acceptance testing is the ideal way to determine if an imaging system's specifications are appropriate for the nuclear medicine department's needs without performing NEMA tests.
Conclusion: The recommendations we offer have been useful for us in testing our most recently acquired single-head, large-field scintillation camera system, but the protocol for acceptance is a highly individual choice and may vary with different departments.
Key Words: Acceptance testing, NEMA, gamma camera, scintillation camera.

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This is the first article in a three-part series on Equipment Quality Control. Upon completion, the technologist will be able to describe the purpose of NEMA standards, list and define the parameters for single-head/single-crystal camera acceptance testing and outline a protocol for acceptance evaluation.

Gamma camera systems are chosen based on departmental needs and the specifications which the manufacturers define as the camera performance characteristics. Once the camera is delivered and installed, verification of the camera specifications constitutes the first quality control test which is performed on the system. The National Electrical Manufacturers Association (NEMA) standards for "Performance Measurements of Scintillation Cameras" provides uniform criteria for manufacturers to use in specifying performance parameters (*1*). These tests involve specialized phantoms and equipment and it is not always possible or practical for the consumer to use them as the protocol for acceptance testing (*2–4*). The manufacturer's specifications for the camera chosen are most often measured against the NEMA standard, but the individual camera delivered to the customer should be evaluated to verify that the camera meets the performance level defined in the purchase order (*2*). These tests become the customer's criteria for accepting the camera from the manufacturer.

Properly performed acceptance testing is the optimal way to assess specifications of a scintillation camera without actually performing NEMA testing protocols. Certainly NEMA protocols may be used, but the time required is extensive, and special NEMA test phantoms and a multichannel analyzer interface to the camera are required (*4*). The following is our protocol for evaluating individual camera performance parameters as an acceptance test for a newly installed system, using the principles of the NEMA guidelines, if not the actual test. These procedures are utilized to ensure that the camera delivered will perform to the standards based on which the system was selected. A physicist should verify the results obtained.

SPATIAL RESOLUTION

The NEMA definition of spatial resolution outlines the intrinsic ability of the camera to accurately detect the original location of a gamma ray on an x-y plane. The NEMA standard calls for spatial resolution to be measured in both the x and y direction and to be expressed as the full width at half maximum (FWHM) and full width at tenth maximum (FWTM) of a line-spread function measured in millimeters. This measurement as performed by NEMA standards requires a special slit phantom, but extrinsic calculations may be performed for all collimators using a ^{99m}Tc point source in a capillary tube.

The source is imaged at various locations along the x and y axes and line-spread functions are generated. Manual calculations of FWHM and FWTM can then be performed. Some nuclear medicine computer systems include programs for this testing, but as long as a line-spread function can be generated, the extrinsic spatial resolution for each collimator can be measured and compared to manufacturer specifications. Using two point sources in capillary tubes imaged at variable distances from each other can determine the limit of the camera/collimator spatial resolution. The sources are

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based at variable distances closer and closer together along a ruler until the two points can no longer be distinguished as distinct separate sources. The limit is the distance at which two separate points can no longer be distinguished as separate, both visually and by peak position. In addition, bar phantom images can be evaluated subjectively for the intrinsic resolution of the camera system and extrinsically for each collimator. It is important that the bar phantom have bar spacing relevant to the resolution parameter specified by the manufacturer.

UNIFORMITY

Intrinsic uniformity is measured with a point source at least five useful fields of view (UFOV) from an uncollimated camera, providing a <1% variation in the flux of radioactivity viewed by the camera crystal. Most modern camera systems use some form of uniformity correction over the raw pattern because the intrinsic flood is not inherently uniform. Uniformity is sacrificed in order to make some gain in spatial resolution by most modern camera systems (*5*). With the advent of digital processors, most modern camera systems correct for this nonuniformity with linearity correction maps and energy correction algorithms so that uniformity and resolution are both preserved (*6*). To evaluate the tuning of the PM tubes and the accuracy of the correction maps, both uncorrected and corrected uniformity flood fields should be at least visually evaluated. The NEMA standard calls for changes in count density over the UFOV to be <5%. Some camera manufactures provide software that allows for an approximation of this standard. Intrinsic flood fields should be collected and at least visually evaluated for all commonly used isotopes to ensure that corrections collected with one isotope (usually ^{99m}Tc or ^{57}Co) remain accurate for other isotope energies.

LINEARITY

Spatial nonlinearities are caused by the mispositioning of individual photon events. This displacement is caused by a limited number of PM tubes trying to locate an infinite number of events and results in a wave-like distortion over the field of view of the system. The manufacturer uses a correction algorithm to compensate for this inherent distortion. The NEMA standard uses the same phantom utilized for spatial resolution testing, i.e., the slit phantom, to collect an image for evaluation. Determination of line-spread function peak positions are then compared to an ideal grid. A subjective evaluation of spatial linearity can be done by checking the straightness of the lines in the bar phantom image obtained for spatial resolution.

ENERGY RESOLUTION

A camera's intrinsic energy resolution may be described as the ability of the camera to accurately identify photopeak events differing in very small energy amounts. The results are expressed as a ratio of FWHM-to-photopeak energy as a percentage. Routinely this will be 9%–11% for ^{99m}Tc for most camera systems. The data are collected with an uncollimated camera positioned at least five useful fields of view away from a point source. If possible, this data should be collected on a multichannel analyzer with at least 50 channels at the FWHM range, as recommended in the NEMA standard.

COUNT RATE PERFORMANCE

All sodium-iodide detection systems have an inherent dead time which should be evaluated during acceptance testing. This is often a major parameter in the selection of a camera, especially with renewed interest in cardiac first-pass studies. The maximum count rate can be determined by observing the count rate while a source is moved toward the uncollimated camera face, through the maximum observed count rate, until the count rate falls. This technique simulates adding small equal aliquots of activity to a source with unchanging distance from the camera. Counts per second are plotted versus distance, where distance becomes the equivalent of increasing activity (Fig. 1).

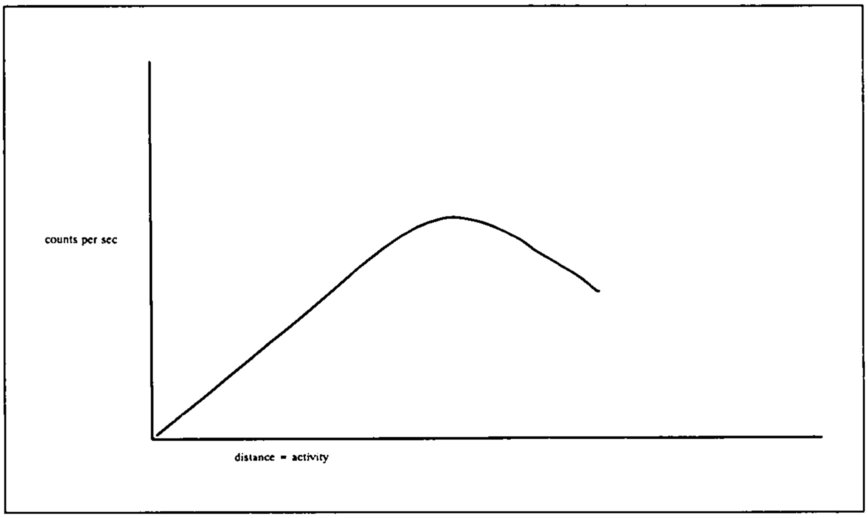

FIGURE 1. Example of hypothetical count rate performance curve.

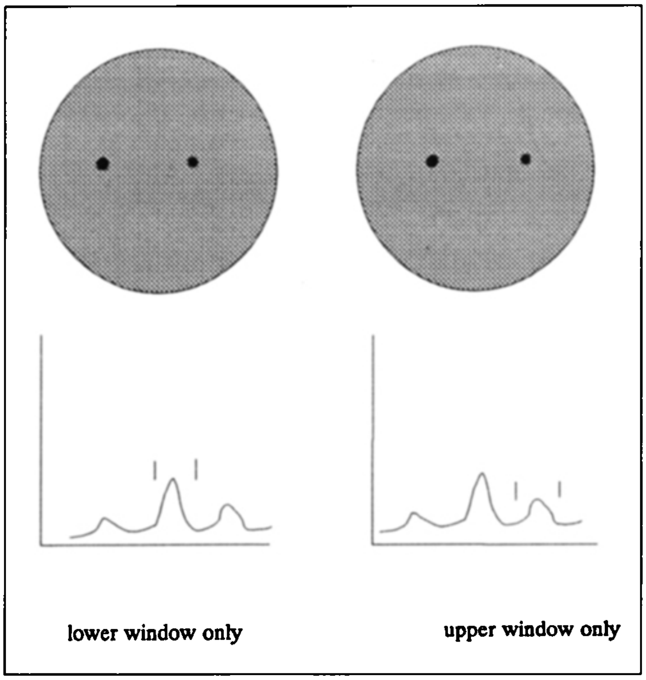

FIGURE 2. Example of separate images of two point sources created with different energy window settings without moving the point sources for the evaluation of multiple window spatial resolution.

MULTIPLE WINDOW SPATIAL REGISTRATION

When multiple windows are used to create an image, the spatial resolutions of the different energies are added together in the final image. If the spatial registrations for the different energy windows are not positioned properly, the resulting image will have a loss of spatial resolution. By imaging a source using different energy windows and comparing the separately created images, the spatial registration can be visually evaluated (Fig. 2). NEMA standards require four different positions to be used and deviations of the images to be measured in millimeters.

SENSITIVITY

Camera sensitivity is measured with a collimator in place. The calculation is performed as counts per unit time per unit source activity. To follow the NEMA standard, a syringe of activity that will produce no appreciable dead time is measured in a dose calibrator before the source is transferred to a petri dish, and the empty syringe is measured after transfer in order to calculate the activity placed in the dish. The petri dish source is then imaged for a set total count and the time is recorded. Each collimator should be evaluated in this way during the acceptance test with the appropriate radionuclides for the collimator used in each case.

EQUIPMENT DEFECTS

Each collimator should be evaluated by collecting a high-count (60,000,000) uniformity flood. An autoradiograph or x-ray of the collimator will also show any physical defects. The crystal may be evaluated for hydration with off-peak ^{201}Tl imaging. Symmetric high and low off-peak images are created and evaluated for nonuniformities. Hydration appears as hotter spots not seen on traditional uniformity floods.

In summary, the protocol for acceptance of a camera is a highly individual choice and this paper offers only recommendations for your consideration. Also included is a checklist which we used to perform acceptance testing on our most recent single-head large field of view scintillation camera system (Table 1).

TABLE 1
Acceptance Testing at St. Luke's Episcopal Hospital

Spatial resolution	Intrinsic bars
	Extrinsic line-spread function with and without magnification through high-resolution collimator. Calculate line-spread function.
Uniformity	Uncollimated high count floods for ^{99m}Tc and ^{201}Tl.
	Check crystal hydration with high and low off-peak ^{201}Tl floods.
Collimation	High-count density floods through all collimators.
	Sensitivity measurement in counts per minute per mCi through each collimator for a source approximately 4 inches in diameter (petri dish) with a negligible dead time.
Count rate characteristics	Move ^{99m}Tc source toward uncollimated camera in measured increments.
	Plot count rate in counts per second through the maximum count rate.
Energy resolution	Acquire pulse-height spectrum with as many channels as possible.
Multiple peak registration	Using two point sources of ^{67}Ga separated by 4 inches, acquire images with the finest matrix available with each of the individual peaks alone and then summation of the peaks without moving the sources.

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CONTINUING EDUCATION TEST

Gamma Camera Acceptance Testing

For each of the following questions, select the best answer. Then circle the number on the CE Tests Answer Sheet that corresponds to the answer you have selected. Keep a record of your responses so that you can compare them with the correct answers, which will be published in the next issue of the *Journal.* Answers to these test questions should be returned on the Answer Sheet no later than September 1, 1994. Supply your name, address, and VOICE number in the spaces provided on the Answer Sheet. Your VOICE number appears on the upper left hand corner of your *Journal* mailing label. No credit can be recorded without it. A 70% correct response rate is required to receive 0.1 CEU credit for this article. Members participating in the continuing education activity will receive documentation on their VOICE transcript, which is issued in March of each year. Nonmembers may request verification of their participation but do not receive transcripts.

A. *The acronym NEMA stands for:*

101. National Equipment Manufacturers Association.
102. National Electrical Manufacturers Association.
103. National Electrical Machine Assessment.
104. National Equipment Marketing Association.

B. *NEMA standard tests can routinely be performed as acceptance testing by the consumer.*

105. true
106. false

C. *Extrinsic spatial resolution is measured*

107. with a collimator and a point source.
108. with a special bar phantom.
109. without a collimator and with a point source.

D. *If spatial resolution is _____, uniformity is _______.*

110. decreased, decreased
111. increased, decreased
112. increased, stays the same

E. *Data for assessment of energy resolution are collected with an uncollimated camera positioned at least _______ UFOV from a point source.*

113. 2
114. 3
115. 4
116. 5
117. 6

F. *The energy resolution of a camera system is*

118. a measure of gamma energy around the photopeak.
119. expressed as FWHM to photopeak energy.
120. the ability to distinguish photopeak events of different energies.
121. 118, 119 and 120
122. 119 and 120

G. *The average energy resolution (FWHM/photopeak energy) will be _______ for most camera systems.*

123. 10%–12%
124. 12%–15%
125. 20%–25%
126. 25%–30%
127. 50% or more

H. *Intrinsic uniformity should be assessed for each collimator obtained with a new system.*

128. true
129. false

I. *To measure multiple window spatial resolution, _______ may be used.*

130. ^{201}Tl
131. ^{111}In
132. ^{67}Ga
133. ^{99m}Tc
134. 131 or 133
135. 130, 131 or 132

J. *Count rate performance to determine deadtime must be performed prior to sensitivity testing.*

136. true
137. false

K. *Sensitivity is*

138. measured for each collimator
139. cps
140. counts/unit time/activity
141. a check for collimator defects
142. 138, 139 and 140
143. 138 and 140

L. *Acceptance testing need not be done if the manufacturer states that the camera meets NEMA standards.*

144. true
145. false