



American College  
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# Nuclear Medicine

## QC Manual

Physician's Section  
Technologist's Section  
Medical Physicist's Section

2024



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# 2024 Nuclear Medicine Quality Control Manual

## QUALITY CONTROL MANUAL

### Physician's Section

### Technologist's Section

### Medical Physicist's Section

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# ACR Nuclear Medicine Quality Control Manual

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### CITATION

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The Nuclear Medicine Accreditation Program of the American College of Radiology (ACR) was established in 1999 to attest to the quality and safety of Nuclear Medicine practice at accredited facilities. Accreditation received through this program assures patients, referring physicians, and others that Nuclear Medicine studies at accredited sites are only performed by well-trained and competent personnel using properly functioning equipment.

All sites accredited by the ACR in Nuclear Medicine have agreed to carry out a continuous program of equipment quality control (QC). The Committee on Nuclear Medicine Accreditation receives many inquiries regarding what would constitute an adequate Nuclear Medicine equipment QC program and what the appropriate roles of various health care professionals at these clinics should be.

This manual is designed to assist facilities in testing and maintaining their Nuclear Medicine equipment in accordance with the broad principles delineated in the [ACR–AAPM Technical Standard for Medical Physics Performance Monitoring of SPECT-CT Equipment](#), [ACR–AAPM Technical Standards for NM Physics Performance Monitoring of Gamma Cameras](#), and [AAPM Report No. 177 Acceptance Testing and Annual Physics Survey Recommendations for Gamma Camera, SPECT, and SPECT/CT Systems](#). The committee has applied these principles to describe which personnel are responsible for which specific tasks and delineate methods for evaluating equipment performance. Some QC tests use standard Nuclear Medicine QC phantoms and/or test tools, and other tests use the ACR Nuclear Medicine phantom.

Members of the ACR Subcommittee on Nuclear Medicine Accreditation physics and non-committee member volunteers who generously donated their time and experience to produce the NM Quality Control Manual are listed on the title page. Special thanks to the staff of the Department of Quality and Safety at the ACR and particularly those that work in the Nuclear Medicine Accreditation Program who have kept this project and the Nuclear Medicine ACR accreditation programs on track over the years.

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ACR Committee on Nuclear Medicine and PET Accreditation

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## I. Purpose and Scope

This manual is designed to help guide facilities establish and maintain an effective Nuclear Medicine (NM) quality control (QC) program. All facilities must recognize the importance of a QC program in producing high-quality diagnostic images at the lowest appropriate dose to the patient. The tests in this manual are not intended to ensure that a gamma camera meets the manufacturer's specifications at the initial installation. Such testing is covered by acceptance testing and is beyond the scope of this document. Instead, this manual provides a minimum set of tests required to ensure that a camera performs in a consistent manner and yields acceptable images. If a camera fails any of the tests specified within this manual, or if performance degradation is observed, the facility should further investigate to determine the cause of the failure or degradation. If the camera's performance is found to be unacceptable, appropriate service should be obtained. Regardless of the quality of an image produced by a gamma camera system, a poor-quality diagnostic workstation can produce (or cause) a poor diagnostic result. The ubiquity of workstations and the breadth of devices used for image interpretation add great complexity to establishing a QC program for these devices. Although QC of workstations associated with image acquisition and processing are addressed in this document, quality of workstations used for image interpretation is beyond the scope of this document.

## II. Introduction to this Manual

NM is a widely used imaging method. However, there is significant variability in the quality of NM imaging performed at different sites. Achieving the full potential of NM requires careful attention to quality assurance (QA), both in regard to equipment performance and in the execution of imaging studies. Each ACR accreditation program is designed by physicians, medical physicists, and technologists who are clinically practicing in that modality. The programs are not only self-assessments for facilities as they complete the application and submission processes but also programs for clinical practitioners to have their practice assessed by their peers. This program follows the approach of previous ACR accreditation programs, which establish practices and standards for QC as part of a QA program. Routine QC can help ensure the equipment is operating appropriately to ensure reliable performance that adequately meets image quality criteria for the NM imaging studies performed. Furthermore, careful development and routine review of clinical protocols by a team that includes the supervising physician, the medical physicist, and the lead NM technologist will also help to ensure optimization of protocol parameters to address the clinical question at hand while avoiding the inadvertent use of an inappropriate dosage, image acquisition, and/or processing parameters.

The ACR develops and maintains [Appropriateness Criteria](#) and specific guidelines and standards related to NM. With improved standards, widely accepted acknowledgement of the value of accreditation, and a growing body of criteria underpinning NM practice, the ACR

Committee on NM Accreditation recognizes the need to reassess the mechanisms by which a radiology department or NM clinic maintains high quality over time. Quality patient care is the responsibility of the entire radiology group, which includes the NM supervising physician, NM technologists, qualified medical physicists (QMPs), nurses, and other physicians. With this comes the understanding that everyone plays a part in maintaining quality and guaranteeing beneficial outcomes. The process, rather than the individual, is the focus of continuous QA.

A vigorous and adaptive QA program is key to a continuous quality improvement program. In this NM Quality Control Manual, the Physician's Section describes the physician's responsibilities in an ongoing NM QC program. The NM supervising physician (interpreting physician) is responsible for ensuring that all QA requirements are met. The QMP is responsible for overseeing all equipment-related QA practices. The QC technologist is specially trained and given responsibility to conduct QA activities appropriate to his or her role.

Details of the QC tests to be performed by the technologist and the QMP are given in two sections. The stated frequency for QC tests is a minimum frequency. A test should be done more frequently when it is being introduced and whenever inconsistent results are found. In addition, it is important to adopt the attitude that QA is a continuous, not episodic, process. An effective QC program will not eliminate all problems, but it will help identify problems before they affect clinical results. QC in NM image-guided therapy is not addressed in this manual.

On initial release of this manual, all facilities applying for accreditation must maintain a documented QC program and comply with the minimum frequencies of testing outlined in this manual. The QMP may require more frequent testing and increased procedure requirements as they see fit (eg, high flood uniformity counts or more frequent bar phantoms). The ongoing QC program assesses relative changes in system performance as determined by the technologist, QMP, or supervising physician. A QMP must be responsible for overseeing the equipment QC program and for monitoring performance on installation and routinely thereafter. All facilities applying for accreditation or renewal must demonstrate compliance with ACR NM QC requirements by including a copy of the facility's most recent Annual NM System Performance Evaluation Summary Form. The evaluation should be dated within 1 year (and must be dated within 14 months) of the date that the facility submitted its application for ACR NM accreditation. Facilities should refer to their state and local regulations to remain in compliance when these are more restrictive. The determination of additional QC testing to be performed to comply with state and local regulations should be determined by a QMP. If an ACR accredited SPECT-CT unit is used for diagnostic CT examinations, it must be accredited separately for CT.

### III. Definitions

#### A. Quality Management Team

There are many facets to a successful QA program, such as efficacy studies, continuing education, QC, preventive maintenance, safety and radiation safety, and equipment calibration. An essential part of the QA program is the quality management team (QMT). This group is responsible for overseeing the QA program, setting goals and direction, determining policies, and assessing the effectiveness of QA activities. The QMT should consist of the following:

- a) Supervising NM physician
- b) Qualified medical physicist
- c) QC technologist
- d) Additional personnel, if desired and appropriate

#### B. Quality Assurance

QA is a comprehensive concept that comprises the oversight and management of practices developed by the QMT led by the supervising physician to ensure that:

- a) Every imaging procedure is necessary and appropriate to the clinical objective.
- b) The combination of acquisition parameters, procedures, and dosages used for each examination is appropriate to address the clinical objective.
- c) The images generated contain information critical to achieving the clinical objective.
- d) The recorded information is correctly interpreted and made available in a timely fashion to the patient's physician.
- e) The patient's risk from the examination is minimized and consistent with the objectives listed in this section.

#### C. Quality Control

QC is an integral part of QA. QC is a series of distinct technical procedures that identifies defects or imperfections in the imaging system that might need remediation to ensure the production of high-quality diagnostic images. Four steps are involved:

- a) Acceptance testing to detect defects in equipment that is newly installed or has undergone major repair.
- b) Other tests done during acceptance testing to establish baseline equipment performance for comparison during annual testing.



- c) Routine performance testing for detection and diagnosis of changes in equipment performance before it becomes apparent in images.
- d) Follow-up testing to verify that the causes of deterioration in equipment performance have been corrected.

Acceptance testing on the NM Camera system should take place before routine patient scanning is initiated. Components replaced or repaired as part of a major repair should be tested before the system is used clinically. Major repairs include but are not limited to detector, crystal, or collimator replacement. The acceptance testing and additional tests after major repairs should be more comprehensive than routine QC testing. All records should be accessible from a location near the NM gamma camera(s); decentralized access to records (eg, web-based records) is also acceptable.

Specifics of the QC program for NM are provided in this manual.

## D. Table of Abbreviations

Abbreviation	Definition
AAPM	American Association of Physicists in Medicine
Bq	Becquerel
cd	Candelas
CFOV	Central Filed of View
COR	Center of Rotation
CPS	Counts per Second
CT	Computed Tomography
CZT	Cadmium Zinc Telluride
ECT	Emission Computed Tomography
FOV	Field of View
FWHM	Full-width at Half-Maximum
keV	Kilo-electron Volts
M	million
MBq	mega-Becquerel
$\mu$ Ci	micro-Curie
mCi	milli-Curie
MDA	Minimum Detectable Activity
MHR	Multi-Head Registration
NEMA	National Equipment Manufacturers Association

Abbreviation	Definition
NM	Nuclear Medicine
NRC	Nuclear Regulatory Commission
PMT	Photo-multiplier Tube
QA	Quality Assurance
QC	Quality Control
QMP	Qualified Medical Physicist
QMT	Quality Management Team
SMPTE	Society of Motion Picture and Television Engineers
SPECT	Single-Photon Emission Computed Tomography
SPECT-CT	Single-Photon Emission Computed Tomography-Computed Tomography (hybrid imaging system)
TG	Task Group
UFOV	Useful Field of View



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# Nuclear Medicine

## QC Manual

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## Introduction

High-quality Nuclear Medicine (NM) images are essential for patient care. A quality assurance (QA) program that is properly designed and consistently executed is necessary to ensure optimal image quality. This manual was developed to help facilities establish and maintain an effective NM Quality Control (QC) program.

The NM Physician's Section describes the responsibilities of the supervising physician in the QA program as defined in the definition section of this document. The QA program includes equipment QC (including routine QC performed by technologists and annual equipment checks by a qualified medical physicist (QMP)), preventive maintenance on equipment, equipment calibration, continuing education, radiation safety, and adherence to Nuclear Regulation Commission or state regulations pertaining to NM.

The supervising physician has the overall responsibility of ensuring that all QA program requirements are met. The QMP oversees all equipment-related QC programs, including annual physics testing. The QC technologist has the responsibility to conduct the daily or other routine QC procedures. Details of the responsibilities of the QMP and QC technologist are provided in their respective sections of this manual and are briefly outlined in this section.

An important part of the program is the quality management team (QMT). The QMT has oversight of the QA program, sets goals, determines policies, and assesses the effectiveness of QA activities.

### Equipment Quality Control

QC is an essential part of QA. QC consists of distinct tests or procedures designed to identify defects or problems with the equipment function that could impact image quality. The equipment includes the imaging equipment itself (gamma cameras) as well as non-imaging equipment used in a NM department, such as dose calibrators, well counters, and thyroid uptake probes.

The components of QC are:

- a. Acceptance testing to detect problems with new equipment or equipment that has undergone major repair and establish baseline performance benchmarks to be used during annual evaluation of the equipment.
- b. Routine QC to detect problems or changes in equipment performance before they affect image quality, patient care, or personnel safety (eg, imaging, correct measurement of radioactivity administered to patient, or regulatory requirements related to radiation safety).
- c. Follow-up measurements or tests to ensure that problems with equipment performance have been corrected.

The annual physics survey must be dated within 14 months of the prior annual survey. The determination of additional QC testing to be performed to comply with state and local regulations should be determined by a QMP.

## Physician's Responsibilities

### A. Supervising Physician

The supervising physician must meet the qualifications for interpreting NM studies. The supervising physician is responsible for the accreditation in that modality and the image quality at their site.

The supervising physician's responsibilities include:

- a. Be responsible for overall management and QA standards. In conjunction with the QMP and the lead NM technologist, maintain a program of QC and continuous quality improvement.
- b. Prepare a policy and procedure manual, review at least annually, and update if needed. This can be accomplished by appointing a policy and procedures team and providing oversight. This should include policies and procedures for dealing with pregnant or potentially pregnant patients.
- c. Prepare a patient protocol manual, review at least annually, and update when needed. This can be accomplished by appointing a protocol review team to provide oversight and establish a review process that ensures protocols are reviewed with appropriate frequency. The review frequency should be consistent with federal, state, or local regulations.
- d. Develop a QA procedure manual in collaboration with the QMP and QC or lead technologist that is available to all staff members. The manual should include:
  - i. Description of the required QA procedures along with required frequency of performance for all equipment, both imaging equipment and non-imaging equipment, such as thyroid probes, well counters, etc.
  - ii. Description of acceptable results and how results will be documented and maintained.
  - iii. Procedures for proper use and maintenance of equipment.
  - iv. Description of orientation program for operators of equipment.
  - v. Documentation of where records are maintained of corrective actions taken as a result of QC testing as well as records of major repairs and upgrades.
  - vi. Description of radiation safety procedures in accordance with federal and state regulations.
- e. Review the laboratory safety manual with the radiation safety officer at least annually.
- f. Ensure that personnel have adequate time to perform the required QC and that a procedure is in place to report any problems with equipment in a timely manner.

- g. Ensure that a QMP performs acceptance testing of new equipment and annual survey(s) of existing equipment.
- h. Ensure that the QC technologists and the QMP have access to the Technologist's and Medical Physicist's sections of this manual. A brief outline of QC and testing requirements for the technologists and medical physicist is provided in this section.

The QMP should send reports for the annual equipment surveys to the supervising physician and the lead technologist. The supervising physician must be made aware of any significant problems.

#### **B. All Interpreting Physicians**

Responsibilities of all interpreting physicians include:

- a. Ensuring protocols are followed.
- b. Reviewing with the technologist any image quality problems identified during interpretation of clinical images.
- c. Following the facility's procedures for reporting and/or corrective action if images are of poor quality.
- d. Participating in facility's practice improvement program.
- e. Providing documentation of current qualifications for practice in accordance with ACR accreditation and state and local rules.

#### ***Interpretive Quality Assurance***

All interpreting physicians should participate in the facility's QA, peer review, or peer learning process(es) for assessing the quality of NM image interpretation. This can be accomplished by participating in ACR's RADPEER or another program.



## Qualified Medical Physicist's Responsibilities

The Medical Physicist's Section of this manual describes in detail the responsibilities of the QMP.

A high-level summary of medical physicist responsibilities is as follows:

- a. Baseline measurements and action limits
  - i. The QMP is responsible for supervising the QC program for the equipment in an NM facility. This includes establishing baseline measurements for equipment performance and action limits that trigger corrective action.
- b. Equipment purchase specifications
  - i. The QMP should assist the site with determining the equipment specifications needed to perform the desired clinical tasks.
- c. Acceptance testing
  - i. Acceptance testing is performed on new equipment and is done prior to initial clinical use. It should establish that the equipment meets the specifications provided by the manufacturer. It also establishes baseline performance standards.
- d. Annual survey (see below)

### A. Medical Physicist Annual Survey (Summary)

#### 1. Physical Inspection and Mechanical Tests

- a. Scanner mechanical inspection
  - i. Physical condition including collimator inspection
  - ii. Safety mechanisms and interlocks
  - iii. Gantry and table movements (translation, rotation, etc)
- b. Workstation monitors for acquisition/processing of images
  - i. Luminance measurement
  - ii. Luminance uniformity
  - iii. Resolution (analog monitor)

#### 2. Planar Gamma Camera Testing

- a. Energy verification (peaking)
- b. Intrinsic flood field uniformity

## IV. Qualified Medical Physicist's Responsibilities

- c. Extrinsic flood field uniformity
- d. Intrinsic off-peak flood field uniformity (recommended)
- e. Energy resolution
- f. Count rate performance
- g. System sensitivity
- h. Spatial resolution and spatial linearity (intrinsic and extrinsic)

### 3. SPECT

- a. Image quality with ACR phantom
  - i. Spatial resolution
  - ii. Uniformity
  - iii. Contrast detectability
  - iv. Attenuation correction
  - v. Artifact evaluation

### 4. Hybrid SPECT-CT Systems

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### 5. Ancillary Equipment

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- b. Uptake probe and well counters
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  - ii. Constancy
  - iii. Chi-square
  - iv. Minimum detectable activity

## Technologist's Responsibilities

The Technologist Section of this manual describes in detail the responsibilities of the NM technologist(s) in the QA program. Technologist responsibilities include acquiring QC data at specified regular intervals (daily, weekly, etc), recording the QC data, maintaining QC records, and initiating corrective action when needed. An abbreviated summary of the QC tests required is as follows:

### 1. Gamma Camera Quality Control

- a. Daily
  - i. Basic visual inspection for obvious damage
  - ii. Energy peaking
  - iii. Detector flood uniformity—intrinsic or extrinsic
- b. Periodic
  - i. Spatial resolution and linearity—intrinsic or extrinsic bar pattern image
  - ii. Detector alignment test. This can include a center of rotation test and any calibration or alignment recommended by the manufacturer for technologists to perform. Center of rotation applies to conventional gamma cameras performing SPECT.
  - iii. Assessment/calibration of field uniformity following vendor recommendations.
  - iv. SPECT image quality using ACR-approved SPECT phantom (quarterly recommended).

### 2. Dose Calibrator Quality Control (Daily When in Clinical Use)

- a. Background activity check
- b. Constancy

### 3. Thyroid Uptake Probe & Well Counter Quality Control (Daily When in Clinical Use)

- a. Energy peaking
- b. Background check
- c. Constancy/efficiency check

### 4. Other Quality Control

SPECT-CT systems have additional QC requirements for the CT subsystem, which the technologist must also perform daily and other periodic QC, as applicable. If the CT subsystem is accredited separately, the ACR CT QC Manual describes QC requirements. If it is not accredited, the QMP must develop a CT QC program, which may follow the manufacturer's specified QC.



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## Introduction

All accredited facilities must maintain a documented quality control (QC) program and must comply with the minimum frequencies of testing outlined in this manual. The ongoing QC program assesses relative changes in system performance as determined by the technologist, service engineer, qualified medical physicist (QMP), or supervising physician. A QMP is responsible for overseeing the equipment QC program and for monitoring performance on installation and routinely thereafter. Facilities should refer to their state and local regulations to remain in compliance when these are more restrictive. The determination of additional QC testing to be performed to comply with state and local regulations should be determined by a QMP.

The quality management team (QMT) is described in the Preface. It is important that the QMT work together and communicate when questions arise. Each should be aware of the others' responsibilities, especially as they relate to their own.

This section of the manual describes the NM technologist's duties in the QC program. They can be carried out with a reasonable investment in time and equipment. The technologist's responsibilities include regularly acquiring QC data, recording the data in QC records, and initiating appropriate corrective action as needed.

### General Quality Control

The purpose of QC is to detect changes in the performance of a gamma camera system that can adversely affect the interpretation of clinical studies. There are obviously a large number of factors that contribute to the final image quality, including uniformity, resolution (both spatial and energy), collimation, count rate performance, and the display monitor or hardcopy device. With the addition of tomographic imaging comes an additional suite of parameters that can influence clinical images. Compared with planar imaging, SPECT requires more stringent field uniformity and is affected by system center of rotation (COR), gantry and collimator hole alignment, rotational stability of the detector head, and the integrity of the reconstruction algorithms. On a day-to-day basis, there is a limited amount of time that can be reasonably devoted to system QC. Hence, the main goal of a QC program should be to monitor those parameters that are (a) most sensitive to changes in system performance and (b) most likely to impact clinical studies.



## Data Interpretation

When performing daily or periodic QC, the technologist reviews images and QC measures and determines whether to proceed with clinical imaging or to take other corrective actions (such as repeating the QC test, consulting with the QMP, performing a calibration or calling for a service engineer). For the technologist to perform this duty, the QMP must establish pass/fail criteria for each QC test in accordance with manufacturer recommendations. The QMP should be available to assist the technologists in determining the appropriate corrective action. Records of QC tests must be maintained by technologists. In addition to verifying compliance with the QC program, such records are valuable to the QMP and service engineer in diagnosing specific issues. Documentation must be stored as either a hard copy (for example, in a binder) or as a file on the computer.

### Important Considerations for Using this Manual

#### A. Scanner Designs

Compared with other modalities, NM is unique in its variety of scanner technologies and clinical practice methods. A scanner might be designed as a multipurpose camera with a full field of view (FOV) or as a dedicated organ-specific camera (eg, optimized for imaging the heart). A scanner might be used to acquire planar images only, SPECT images only, or both, depending on its detector design or on a site's clinical needs. Most NM scanners are equipped with parallel-hole collimators to obtain planar views and have a gantry to rotate the detectors for SPECT imaging. However, several scanners use nonparallel collimators (fan-beam, cone-beam), multi-pinhole collimation, or pivoting detectors to optimize sensitivity for clinical applications. Furthermore, although the "Anger camera" design with single NaI(Tl) crystal and large photomultiplier tubes (PMTs) is widely used, certain scanners are equipped with pixelated scintillation crystals, solid-state photosensors, or fully solid-state detectors.

#### B. Quality Control Testing Frequency

NM camera QC is a continuous process performed by a technologist. Throughout the day, a trained NM technologist keeps close watch on image data as they are acquired, looking for potential issues related to the scan procedure (such as patient motion or infiltrated radiopharmaceutical injection) as well as sudden changes in detector performance (such as a malfunctioning PMT). In addition, the technologist performs routine QC on the NM camera on a daily and periodic basis to monitor the camera performance to detect changes over short-term and longer-term intervals.

A site's QC program should account for its scanners' design, performance, and usage. First, the appropriateness of QC tests should be considered for the scanner technology. An obvious example is that a test of planar spatial resolution is not applicable to scanners that are only capable of SPECT imaging. In addition, the frequency of a QC test should consider the stability of the detector technology. For example, compared with older Anger cameras, which use analog electronics to process detected events, newer Anger cameras with digital electronics are significantly more stable. Thus, certain QC tests can be done less frequently with digital Anger cameras.

To assist sites in establishing their QC programs, guidelines for technologist's daily and periodic QC are presented, considering different scanner models. The scanners considered represent the vast majority of those in clinical use at the time of this writing. It is recognized that some uncommon scanners might not be listed and that new scanners will be developed in the future. In these cases, it is recommended that the site's QMP develop the appropriate QC tests and frequency in consultation with the supervising physician, technologists, and manufacturer documentation.

These guidelines specify “Daily” and “Periodic” QC tests. The daily tests are those required to ensure that the scanner is operational with acceptable performance prior to injecting the first patient of the day to be imaged on that scanner. Because the frequency of other QC tests depends on the scanner design or usage, these QC tests are designated as “periodic” and should be specified scanner-by-scanner within the site.

### C. Quality Control Records

QC records must be maintained, with results of QC activities recorded at the time they are performed. The QMP will tailor the QC records/forms according to the specific equipment and the guidelines in this document. Site personnel can develop their own hardcopy forms or use computerized records. Based on size, administrative organization, and QC team’s preferences, facilities’ QC record content will vary. A small facility might have a single record encompassing all of its equipment; a large facility will often have separate records for equipment at different locations. In general, the QC records should include the following:

- a. A section describing the facility’s QC policies and procedures for the equipment covered by the records.
- b. A section of data forms to use when recording QC procedure results for each piece of equipment covered by the records.
- c. A section for recording notes on QC problems and corrective actions.

The QC records must be kept in a location that is accessible and known to all members of the QMT and the service engineer so that they can refer to it when questions arise. The section for recording QC problems and corrective actions can facilitate communication between the service engineer and QMT members who often have different work schedules. QC records for an individual scanner should be kept and be accessible. QC records must be maintained in compliance with local regulations, hospital policies, and accreditation mandates. QC images should be maintained for review as specified by the QMP.

### D. Alternative Procedures

Scanner software and hardware differ between manufacturers and models. By far, the most common scanner design is the Anger camera, but organ-specific cameras and novel technologies are becoming more prevalent. Although many of these QC tests are very standardized, others are described more generally in this document to account for the variety of hardware and software. The QMP should tailor the QC program as appropriate for their laboratory.

### **E. Action Limits**

The QMP sets action limits for QC tests and should be readily available to consult with technologists as needed. Because analysis software differs between scanners, action limits should be specified by the QMP per scanner model as appropriate.

### **F. CT Quality Control (If Applicable)**

In addition to the NM QC program, SPECT-CT systems have additional QC requirements for the CT component. In many cases, the CT portion of the scanner is also accredited, in which case the site follows the procedures described in the CT QC manual. However, if a SPECT-CT system is not accredited for CT, a QMP must develop an appropriate CT QC program for SPECT-CT.

## Summary of Technologist's Quality Control Tests

The following table summarizes the NM Tech QC tests described in this manual. Frequencies are specified by the QMP according to guidelines in this manual. All Daily QC should be performed prior to administering a radiopharmaceutical to the first patient of the workday.

**Table 3-1. Technologist's QC tests and frequencies**

QC test	Frequency	Notes
Basic inspection	Daily	Verify there are no signs of external damage
Daily flood uniformity	Daily	Verify detector function
Energy peaking	Daily	Verify the photopeak stability
Detector tuning	As needed	Based on daily QC results
Spatial resolution/linearity	Periodic (weekly or monthly at minimum)	Frequency depends on camera design
Uniformity verification/calibration	Periodic (typically monthly)	Higher counts than daily flood
Detector alignment verification/calibration	Periodic (typically monthly)	COR, multidetector alignment, etc
SPECT image quality	Semiannually (quarterly recommended)	ACR SPECT phantom
Dose calibrator constancy	Daily	Other QC tests as designated by QMP (refer to Medical Physicist's Section of this manual)
Thyroid uptake probe/well counter QC (as applicable)	Daily (or on days of use)	High-voltage/gain check, constancy, etc

### Technologist's Daily Nuclear Medicine Camera Quality Control

#### A. Purpose

QC must be performed daily to ensure short-term stability of the NM camera, as sudden changes in detector performance can occur. Changes related to detector electronics could be drastic, such as a malfunctioning PMT, which prevents counts being detected over a region of the detector, or a failed circuit board, which prevents counts being detected over the entire detector. Other changes could be subtle, such as a temperature or voltage shift, which causes a tube-pattern nonuniformity over the FOV. There also is the potential for mechanical damage to have occurred among workdays when the camera was unattended. Besides hardware-related issues, the detector can be affected by radiopharmaceutical contamination remaining from a prior study.

Therefore, it is essential that the NM technologists perform daily QC. Daily QC differs from periodic QC, in that its goal is to ensure the camera is suitable for clinical imaging while being performed rather quickly, whereas periodic QC is intended to detect longer-term changes in camera performance.

#### B. Applicability

Daily QC applies to all NM cameras. Note that the methods might differ based on camera design. Although most installed NM cameras are of the Anger camera design, certain cameras with novel detectors or imaging geometries might have specific daily performance checks beyond the scope of this manual.

#### C. Frequency

Daily QC must be performed on each day of use, prior to administering a radiopharmaceutical to the first patient of the workday. Changes in detector performance often occur overnight or over the weekend, and thus the optimal time to perform this QC is at the beginning of the workday. Furthermore, ensuring that the camera is functional must occur prior to injecting the first patient of the workday to avoid unnecessary radiation exposure to the patient if the scan cannot be performed.

In addition to performing daily QC, a technologist should observe image quality throughout the workday because a change in camera performance or radiopharmaceutical contamination can happen at any time.

Some cameras are equipped with automated QC, which can execute at a specified time. This feature is convenient and minimizes technologist duties at the start of the workday. However, technologists should be aware of automated system motions that would occur while the camera is unattended, which have the potential to cause serious mechanical damage if impeded by ancillary equipment positioned near the camera.

### D. Daily Quality Control Procedures

#### 1. Basic Daily Inspection

The technologist should perform a general inspection of the camera and workstation to ensure that no obvious damage or outages have occurred since the previous workday. Basic daily inspection should include, but is not limited to:

- a. Collimator damage.
- b. Damage to the detectors, gantry, or table.
- c. Room environment conditions (eg, temperature, humidity, water damage).
- d. Inspection of the associated workstation and peripheral.

### 2. Energy Peaking

“Peaking” refers to ensuring that the photopeak of the energy spectrum is properly centered within the energy window. For example, a technetium-99m (Tc-99m) photopeak should be centered near 140 keV, or a cobalt-57 (Co-57) photopeak should be centered near 122 keV. A detector's performance could be affected by a change in its high voltage supply, temperature, or other factors, which cause a shift in the detected energy. If a portion of the photopeak shifts outside the energy window, the detector's sensitivity would be reduced, and its uniformity also might be affected. Thus, energy peaking must be done before performing detector flood uniformity.

NM cameras vary in regard to how peaking is performed. Some systems have automated analysis of photopeak location built into its daily flood uniformity procedure (see “3. Detector flood uniformity”), whereas other systems allow a visual check of the location of the photopeak in the displayed energy spectrum acquired with a flood source or point source. The NM physicist specifies an appropriate procedure for the technologist to perform this peaking task.



### 3. Detector Flood Uniformity

An essential task of daily QC is to verify the detector uniformity using a flood or point source. It is important to evaluate the entire FOV of each detector. For Anger cameras, the effect of a malfunctioning PMT is only in the vicinity of the tube, and for pixelated cameras, a malfunctioning detector element results in only a single “cold” pixel. It is not appropriate to use a point source with the collimator installed because only a small region of the detector sees radiation from the source. Instead, the uniformity must be evaluated such that the source illuminates the entire detector:

- a. Intrinsic flood: use a point source with the collimator removed, or
- b. Extrinsic flood: use a sheet source with the collimator installed.

Deciding between intrinsic or extrinsic daily uniformity flood depends on several factors, such as the camera design (eg, ease of removing collimators), technologist workflow, cost (eg, to replace Co-57 flood sources), and risk of damaging collimators or the detector crystal during removal and installation. The technologist and physicist should consider these factors in determining the optimal approach for the laboratory.

Generally, acquiring more counts in a flood uniformity image allows for the detection of more subtle nonuniformities above the noise level however with the trade-off of increased acquisition time. The goal of daily QC is to ensure short-term stability of the camera while being practical for the technologist's workflow prior to injecting the first patient of the workday. At a minimum, the following guidelines are recommended for Anger cameras:

- a. Extrinsic flood uniformity (using a Co-57 sheet source (preferred))
  - i. Large FOV cameras (smallest dimension greater than or equal to 32 cm), acquire a minimum of 4M counts.
  - ii. Small FOV cameras, acquire a minimum of 3M counts.
- b. Intrinsic flood uniformity
  - i. “Far” point source: Placing the point source a far distance from the detector (at least 3 to 5 times the longest dimension of the detector) will allow for near-uniform coverage of the detector FOV. Acquire the same minimum counts as the extrinsic floods: 4M for large FOV, 3M for small FOV.
  - ii. “Near” point source: Some cameras are designed to acquire intrinsic QC flood images with the point source positioned between the 2 detectors and to perform curvature correction to account for the point source profile. In this case there are fewer

counts at the edge of the FOV compared with the center of the FOV. To properly evaluate uniformity of the entire detector, more counts must be acquired: a minimum of 10M for large FOV and 5M for small FOV.

The above guidelines represent a minimum number of counts to be acquired for daily flood uniformity evaluation. More counts allow for more sensitive evaluation of detector nonuniformity, but at increased acquisition time. The technologist should be aware that excessive count rates could cause nonuniformities in the flood image. In establishing the parameters of the laboratory's daily QC program, the QMP should consider manufacturer recommendations and technologist's workflow.

Novel cameras with non-Anger detectors or unconventional collimation have unique requirements for daily flood uniformity, for which general guidelines are not yet well established. The QMP should consult with manufacturer recommendations and camera data to establish appropriate daily flood parameters.

In addition to the acquisition procedure, the QMP should specify pass/fail criteria for daily flood uniformity. A visual evaluation of flood uniformity is the first step, which quickly indicates the presence of a malfunctioning tube or detector element, or a tube-pattern artifact. In many cases, the camera software provides an automated evaluation of flood uniformity, stated as percent uniformity across the useful FOV (UFOV) and central FOV, as well as a QC report (pass/fail). Based on historical data of each camera, the physicist should set quantitative action limits as appropriate to guide technologists on their decision whether to proceed with workday activities. (Note that the software calculation of percent uniformity might differ between scanners, and thus action limits should be specified by camera model.)

#### 4. Detector Tuning (As Applicable)

Many cameras provide a detector tuning procedure for routine use by technologists. Detector tuning might involve balancing the gains of the PMTs or slight adjustment of the calibration tables to improve detector uniformity. The tuning procedure can be a separate workflow, or integrated within the daily QC workflow, or within another calibration workflow (such as detector uniformity calibration).

Because detector tuning is a camera-specific procedure, the physicist should consult with manufacturer recommendations and a service engineer to determine the appropriate frequency and procedure for detector tuning. For example:

*Example (a): Daily QC threshold. The technologist inspects flood images and flood uniformity numbers to determine whether detector tuning should be performed, based on guidelines established by the QMP.*

*Example (b): Periodic QC. A routine schedule is established by the physicist for the technologists to perform detector tuning, such as during daily QC on the first workday of the week.*

*Example (c): Service schedule. The detector tuning is performed by a service engineer during routine preventive maintenance. This approach would be appropriate if the detector tuning procedure might cause performance issues if not performed correctly by a technologist. The QMP would need to establish guidelines for the technologists regarding when a service engineer should be called, based on the daily QC or periodic QC results.*

For a laboratory with multiple cameras, the QMP should specify the appropriate schedule camera by camera.

## E. Technologist's Periodic Nuclear Medicine Camera Quality Control

The frequency of many other QC tests depends on the scanner design or usage. Accordingly, these QC tests are designated as "periodic" QC, as follows:

### 1. Spatial Resolution and Spatial Linearity

**PURPOSE** The goal of periodic spatial resolution and spatial linearity QC is to detect changes in spatial resolution or linearity. The detector uses electronics (analog or digital) along with a spatial calibration to determine the location of the detected event. The accuracy of event positioning might change suddenly, or incrementally, over time. Thus, ensuring the stability and performance of the detector's spatial linearity and resolution is an important part of camera QC.

**APPLICABILITY** Routine QC of the detector's spatial linearity and resolution is essential for Anger cameras, the most common gamma camera design. An Anger camera consists of a large single crystal and an array of PMTs. The spatial location of an event is determined from electronic signals from either a group of PMTs or the entire array of PMTs.

Other pixelated detectors work differently. Pixelated detectors consist of an array of scintillation crystals or solid-state crystals (such as cadmium zinc telluride). Instead of estimating the event position within a single crystal, the electronics of a multicrystal detector determine the individual crystal in which the event most likely occurred. Because the location of each crystal is known, such multicrystal detectors do not require routine QC of linearity and resolution. (Refer to ACR accreditation instructions, which list cameras not requiring planar resolution phantom images.)

**FREQUENCY** The physicist should consider the design of the camera in specifying the frequency. In an Anger camera, the signals from multiple PMTs are processed to compute the spatial position of each event.

In older analog Anger cameras, this event location determination is performed using an electronic signal generated within the detector. Analog Anger cameras are more sensitive to changes in temperature or electrical voltage. For these cameras, a monthly check is required and weekly is strongly recommended. Modern Anger cameras with digital circuitry are more stable. Monthly checks are required for these cameras.

QC to verify the linearity and resolution of a gamma cameras must be performed at least monthly. For older Anger cameras with analog positioning electronics, being less stable than modern digital Anger cameras, a weekly evaluation is strongly recommended.

Regardless of this guideline, some sites are subject to more stringent state or federal requirements specified in their radioactive materials license, which must be followed. The QMP should consider this when establishing the QC program.

## METHODS

### a. Bar phantom

Use a four-quadrant bar phantom that allows for evaluation of spatial resolution according to [ACR accreditation requirements](#). A four-quadrant phantom has four sections of lead bars that are spaced at intervals equal to the four different bar widths, and it provides valuable information about the camera's linearity and spatial resolution. It is important to place the four-quadrant phantom over the entire detector surface because linearity issues typically appear near the edges of the FOV.

A full evaluation of the entire detector surface over time involves acquiring all four orientations of the four-quadrant bar phantom, and it allows the minimally spaced bars to be imaged over the entire FOV. One approach is to acquire all 4 orientations monthly, whereas another approach is to rotate among the 4 orientations month-to-month (it requires the site to remember the previous position used). The physicist should specify the QC procedure based on the camera design (eg, digital versus analog) and its stability, while following state or federal requirements as specified in the site's license (as applicable).

Note: A planar view of SPECT phantom is not suitable for routine QC as it does not indicate linearity over the entire FOV, although it is suitable for evaluating spatial resolution.

### i. Acquisition

Bar phantom images can be acquired extrinsically or intrinsically using either a sheet or a point source respectively. See the [ACR accreditation guidelines](#) for more details.

- Large FOV gamma cameras (smallest dimension greater than or equal to 32 cm): acquire 5M counts with  $512 \times 512$  matrix (if  $512 \times 512$  is not available, then use highest matrix size available).
- Small FOV gamma cameras: acquire 3M counts with  $512 \times 512$  matrix (if  $512 \times 512$  is not available, then use highest matrix size available).

Although intrinsic bar phantom images provide marginally better spatial resolution for evaluation, physicists and technologists should consider the possible risk of detector damage potentially caused by impact of the bar phantom onto scintillation detectors when acquiring intrinsically.

### ii. Evaluation

Inspect the bar phantom images to evaluate the spatial resolution, linearity, and consistency over time. Determine the smallest size bars that are visually resolved from end to end. (Note, sometimes bars are partially resolved, visible in the regions between PMTs but not visible in regions centered on PMTs.) Evaluate the straightness of the bars, particularly near the edges of the FOV. Refer to the [ACR accreditation guidelines](#) specifying acceptable performance:

- Intrinsic bars with Tc-99m or Co-57: should resolve 2.9-mm bars or smaller.
- Extrinsic bars with Tc-99m or Co-57: should resolve 3.4-mm bars or smaller using LEHR (low energy high resolution) collimators.

Other collimators or radionuclides may be used (eg, Tl-201, Ga-67, In-111); refer to the [ACR accreditation guidelines](#). The QMP might specify other criteria, depending on scanner and collimator.

## 2. Detector Uniformity Verification/Calibration

**PURPOSE** Although detector flood uniformity evaluation is part of daily QC, the underlying goal of periodic QC is different. As described above, daily QC seeks a quick and feasible evaluation of camera uniformity to ensure short-term stability and determine that the camera is acceptable for use, prior to injecting the first patient. Cameras often experience long-term degradation in uniformity because of several factors. Routine detector tuning (see daily QC, above) helps minimize long-term changes but is not enough to avoid loss of uniformity because of other factors such as crystal aging or electronic drift.

The goal of periodic QC is to ensure a higher level of stability over longer time intervals, which requires more counts than would be feasible for daily QC.

**APPLICABILITY** Applies to all cameras. (Note: some non-Anger cameras can have unique procedures specified by the manufacturer to ensure uniformity.)

Depending on the manufacturer and model, cameras use different approaches to periodic uniformity QC. Some cameras specify a routine calibration to be performed by the technologist. Other cameras specify a periodic high-count check of the detector uniformity and specify guidelines when a full calibration is appropriate. Some manufacturers reserve calibration procedures for trained field service engineers and do not include calibrations as part of technologist routine QC. The QMP must determine the appropriate periodic QC for the site, which can be specified as a routine calibration or high-count verification of uniformity.

**FREQUENCY** The QMP should specify the frequency of detector uniformity QC based on manufacturer recommendations and the observed stability of the camera. Many manufacturers specify a routine interval for a detector flood calibration or evaluation, such as monthly or weekly. If the manufacturer does not list detector uniformity as part of routine QC, then the physicist should specify the frequency.

**METHODS** Generally, one should follow the manufacturer-specified procedure for each camera, as detector hardware and software can differ significantly.

Otherwise, if the manufacturer does not specify a procedure, the physicist should specify a routine detector flood uniformity scan that acquires a sufficient number of counts to provide a more thorough evaluation than daily QC. For example, the periodic detector uniformity procedure could be to run a daily flood scan with a higher number of total counts instead of 4M counts (minimum for daily QC), with a tighter threshold for pass/fail than for daily QC. The procedure could be performed either by technologists or by a service engineer during routine preventive maintenance. A quantitative evaluation of a flood uniformity verification is useful in determining whether a full uniformity calibration is needed. The QMP should establish action levels per camera for acceptable uniformity.

### 3. Detector Alignment Verification/Calibration

**PURPOSE** Rotating gamma camera SPECT systems require the periodic testing of the detector alignment to ensure reliability of mechanical and electronic centers. Depending on the mechanical design of the camera, this could involve a center of rotation (COR) correction, multiple head registration, angular calibration, detector tilt correction, etc. COR is an imaginary axis about which the detector heads rotate. The COR acquisition is a calibration to ensure and maintain the detector's mechanical and electronic matrix alignment. Misalignment from COR errors or other mechanical errors negatively affects spatial resolution of SPECT images and create artifacts.

**APPLICABILITY** All SPECT systems with detector motion or electronic positioning should have detector alignment verification performed as part of a periodic QC program.

Similar to flood uniformity QC, camera manufacturers may suggest different approaches to detector alignment and COR QC. Many camera manufacturers specify a verification QC procedure to check if the detector alignment is satisfactory and whether a full calibration is needed. Other camera manufacturers specify a routine calibration procedure for detector alignment. The QMP should consider the manufacturer's guidelines when establishing the site's QC procedure.

**FREQUENCY** Detector alignment QC should be performed monthly or more frequently as specified by the QMP in consideration of manufacturer recommendations. It is recommended to follow the manufacturer's camera-specific protocols when performing detector alignment QC and calibrations, as methods can vary significantly between scanner models. Commonly, 1 or more point-sources in the 500 to 1000  $\mu\text{Ci}$  (~18 to 37 MBq) range will be used for the SPECT acquisition. In some cases, separate evaluations of 180° and 90° detector configurations are performed.

**METHODS** In many cases, the camera software provides a detector alignment or COR protocol to test and verify the integrity of the current calibration. The software analyzes the data to evaluate offset and angular-dependent shift between point source projection and calculated matrix location. Software displays deviations are compared with action limits set by the physicist. These results indicate whether a new detector alignment calibration is necessary. Most SPECT systems have integrated software that easily measures and applies corrections automatically.



#### 4. SPECT Image Quality

**PURPOSE** The overall goal of SPECT image quality QC is to ensure the stability and accuracy of the scanner for SPECT imaging. Whereas the other QC tests described in this manual evaluate specific elements of camera performance, the SPECT image quality QC uses a SPECT acquisition of a water-filled phantom to evaluate overall SPECT performance, including detector uniformity, collimator integrity, detector alignment, contrast, spatial resolution, and artifacts.

**APPLICABILITY** All systems that are clinically used for SPECT imaging must have SPECT image quality evaluated.

**FREQUENCY** Semiannually at a minimum (quarterly recommended).

**METHODS** An ACR NM Phantom or Small NM Phantom from an approved manufacturer shall be used. The recommended activity is 10 to 20 mCi (370 to 740 MBq) Tc-99m for the NM Phantom and 5 to 15 mCi (185 to 555 MBq) Tc-99m for the Small NM Phantom. The six spheres must be lined up with the rods and placed in order of increasing size clockwise viewed from the top. Use the highest resolution low energy parallel-hole collimator routinely used for clinical acquisition. The count rate during the acquisition should not exceed 50 kcps for typical Anger cameras. The total count of all images from all heads shall be approximately 32M counts for the NM Phantom and 20M counts for the Small NM Phantom. Follow the [ACR guidelines](#) for the calculation of SPECT acquisition time per view as well as other detailed procedures and requirements.

Image analysis should be performed on SPECT images with a slice thickness of 0.6 to 0.9 cm by summing 2 or 3 slices. Follow ACR guidelines for the [recommended reconstruction parameters](#) as well as the [QC passing criteria](#).

If a SPECT camera is used clinically for quantitative evaluation, it is recommended to include an evaluation of quantitative accuracy in the periodic QC program. Some cameras include specific hardware and software for calibration and QC of quantitative SPECT. In other cases, quantitative SPECT measurements are performed by manufacturer software or third-party software, based on a separate calibration scan of a phantom with known activity concentration. The site's QMP should consult with the manufacturer/software recommendations and develop an appropriate QC program according to the site's use of the product. For example, if a site performs personalized dosimetry for radiopharmaceutical therapy based on activity quantified from SPECT images, a phantom simulating these measurements should be considered.

### 5. Dose Calibrator Daily Quality Control

The Medical Physicist's Section of this manual provides a detailed description of dose calibrator tests. Typically, the NM technologist is tasked with daily QC of dose calibrators, which is described in this section.

**PURPOSE** A dose calibrator is an essential part of any NM department and is used to assay the amount of activity of a radiopharmaceutical in a vial or syringe. The administered activity must be assayed in a properly functioning dose calibrator. This device should be capable of accurately and reliably measuring activity over the full range of clinical use.

**APPLICABILITY** All dose calibrators in clinical use in NM at site.

**FREQUENCY** Daily, prior to first patient's assay.

**METHODS** A background check should be performed as the first step of daily QC. The dose calibrator might show an activity reading (positive or negative) even when the chamber is empty, depending on the previous background compensation or the presence of nearby unshielded sources. If needed, a new background compensation should be performed. In addition, the syringe holder ("dipper") should be checked for contamination before proceeding with the constancy check.

Constancy is a QC test that is performed daily to verify that the calibrator is accurate and reliable for the assay of radiopharmaceuticals prior to administration to a patient. According to Nuclear Regulatory Commission regulations, administered radioactivity must be within  $\pm 20\%$  of the prescribed radioactivity. Some Agreement States might require the radioactivity to be within  $\pm 10\%$ . It is the obligation of the person measuring the radioactivity, typically the NM technologist, to confirm the assay meets the requirements.

A long-lived source should be used as a daily check to confirm the constancy of the dose calibrator response. Sealed vial radioactive sources, typically Co-57 or cesium-137 (Cs-137), are commonly used for this purpose. The vial is placed in the chamber of the dose calibrator and activity is measured using the channel that matches the type of radioactive sources and recorded.

Procedure Steps:

1. Perform background check with the calibrator chamber empty and record the reading.
2. Place the sealed vial source into the chamber of the dose calibrator.

## VI. Technologist's Daily Nuclear Medicine Camera Quality Control

3. Measure the source on the proper isotope channel and record the reading.
4. Leave the vial source in the chamber and select alternate channels of commonly used isotopes in the department, recording each reading.

These recorded values are compared to previous results to determine if the dose calibrator is performing consistently. The QMP should set an acceptable range for the test results based on the reference activity, corrected for decay. The NRC requires that the dose calibrator be removed from service if variations are greater than  $\pm 10\%$ .

## 6. Thyroid Uptake Probe & Well Counter Quality Control

The Medical Physicist's Section of this manual provides a thorough description of testing of thyroid uptake probes and well counter systems (as applicable). Typically, the NM technologist is tasked with daily QC of these systems, which is the topic of this section.

**PURPOSE** Thyroid uptake probes and clinical well counter systems are used for high sensitivity counting of in vivo organs or clinical specimens (eg, blood samples), respectively.

**APPLICABILITY** All thyroid uptake probes being clinically used in NM at site.

If a site performs clinical assays of specimens, then this applies to those well counters in use for this task.

**FREQUENCY** The uptake probe and/or well counter should be QC tested daily (or at least each day of clinical use).

**METHODS** QC includes Energy Peaking, Background Measurement, and constancy. Results should be recorded.

Energy Peaking checks the energy spectrum to verify that the photopeak of the radionuclide coincides with the preset photopeak energy window within a  $\pm 10\%$  range.

A Background measurement is performed by placing an empty tube or vial in the probe or well counter to determine the current background activity.

Constancy QC is performed by placing a long-lived source in the designated location (in the probe's or counter's source holder, or in front of the probe) to confirm the instrument is accurately and reliably measuring well counter response. Values should be within  $\pm 10\%$  of expected.

## F. Additional Resources

In addition to equipment operator manuals, the following resources provide helpful information on NM camera QC:

- Zanzonico P. Routine quality control of clinical nuclear medicine instrumentation: a brief review. *J Nucl Med*. 2008;49(7):1114-1131. doi: 10.2967/jnumed.107.050203
- EANM Physics Committee; Busemann Sokole E, Płachcńska A, Britten A, et al. Routine quality control recommendations for nuclear medicine instrumentation *Eur J Nucl Med Mol Imaging*. 2010;37(3):662-671. doi: 10.1007/s00259-009-1347-y
- MacFarlane CR; American College of Radiologists. ACR accreditation of nuclear medicine and PET imaging departments. *J Nucl Med Technol*. 2006;34(1):18-24.
- European Association of Nuclear Medicine (EANM). Quality control of nuclear medicine instrumentation and protocol standardisation (2017). EANM. Published October 2017. Accessed October 25, 2024. [https://eanm.org/wp-content/uploads/2024/06/EANM\\_2017\\_TEchGuide\\_QualityControl-1.pdf](https://eanm.org/wp-content/uploads/2024/06/EANM_2017_TEchGuide_QualityControl-1.pdf)

### Links to select relevant ACR materials

- [ACR NM phantom instructions](#)
- [ACR phantom criteria for evaluation](#)
- [ACR NM/PET Phantom Image Atlas](#)





American College  
of Radiology™



# Nuclear Medicine

## QC Manual

Medical Physicist's Section

2024

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## Introduction

Nuclear Medicine (NM) is a modality that involves diagnostic imaging, radiopharmaceutical therapies, and other non-imaging studies. A wide variety of equipment is used to perform NM studies. Ensuring appropriate equipment performance and achieving high-quality imaging studies requires careful attention to high-quality standards of practice based on Nuclear Regulatory Commission and state regulations, ACR appropriateness criteria and guidelines, recommendations from other related societies and agencies, and also institutional policies and standard operating procedures.

The success of NM imaging depends largely on producing high-quality diagnostic images. Although equipment service engineers ensure the system is performing within manufacturer's specifications and technologists perform specified calibrations and quality control (QC), the qualified medical physicist (QMP) is uniquely qualified to perform certain tests and then analyze the data to determine which sets of specifications are relevant to a particular imaging problem. The QMP provides the bridge between the technical aspects and how they relate to the clinical image quality of the system. The QMP's testing helps to recognize equipment failures before clinical images are unacceptably degraded. The QMP can also perform tests to determine if imaging irregularities can be attributed to procedural or equipment errors. The QMP's tests are also useful in determining if the design specifications and performance characteristics of an NM scanner are sufficient and optimized for the intended clinical practice.

The ongoing QC program assesses relative changes in system performance as determined by the technologist, QMP, or supervising physician. A QMP must be responsible for overseeing the equipment QC program and for monitoring performance upon installation and routinely thereafter. All facilities applying for accreditation or renewal must demonstrate compliance with the ACR QC requirements by including a copy of the NM Equipment Evaluation Summary form from the most recent Annual NM System Performance Evaluation for each unit at the facility. The evaluation is to be performed annually (within 12 to 14 months). Facilities should refer to their state and local regulations to remain in compliance when these are more restrictive. The determination for any additional QC testing that might need to be performed for compliance with state and local regulations should be made by the QMP.

It is the responsibility of the QMP conducting these tests to accurately convey test results in a written report, make recommendations for corrective action according to the test results, and review the results with the radiologists and technologists working on each scanner, when appropriate. Communicating test results and recommending corrective action are areas that should be given focused attention, as this is a vital interface between the technical assessment and the clinical practice. Corrective action should not be limited to repair of NM equipment by a qualified service engineer. It should also include recommendations concerning use of the NM scanner, protocol optimization, image

processing, viewing conditions, and the QC program. The QMP must periodically review the results of the routine QC tests conducted by the technologist and make recommendations regarding these tests. If the manufacturer-provided test result is outside the manufacturer's specification, or there is believed to be a clinically significant degradation of image quality on the images used for diagnosis, service should be contacted.

In addition to the gamma camera (and CT subsystem, as applicable), it is the responsibility of the QMP to ensure that non-imaging equipment, such as the dose calibrator and uptake probe, are operating properly and within specifications; therefore, the applicable QC testing should be appropriately performed. Although some of the tests should be performed by the QMP, other tests are typically performed by the technologist as part of routine QC. Those tests should be verified by the QMP as part of the comprehensive evaluation of equipment performance.

Communication among the QMP, the supervising NM physician, and lead/supervising technologist is key for reporting equipment issues discovered during testing and for appropriately initiating corrective action. The QMP has a responsibility to provide information as detailed as possible regarding the following aspects of a detected problem:

- a. The specific metric/issue under consideration and how it affects the operation/performance of the system
- b. The specific tests that have been performed, including phantoms, if used
- c. The observed/measured results
- d. The specifications (eg, manufacturer's specifications) not being met
- e. How it could potentially affect clinical performance
- f. Specifically defining any limitations related to using the equipment in its full or partial capacity and how the occurred problem might affect image quality.

The site has the responsibility to ensure that effective and timely corrective action is performed and documented and that any comments or recommendations for quality improvement are addressed. If corrective action was performed, this manual recommends that verification by the QMP is performed in communication with the site.

## Medical Physicist's Responsibilities

### A. Quality Control Test Criteria and Action Limits

The QMP is responsible for supervising and overseeing the implementation of a QC program for the equipment in a NM facility. Instituting a QC program should be accomplished in collaboration with the supervising NM physician and the lead/supervising technologist. The QMP is responsible for establishing baseline QC measurements and action limits, which are thresholds or tolerance levels of QC results that, if exceeded, would trigger the requirement for corrective action. Corrective action includes, but is not limited to, contacting service personnel and appropriately addressing equipment-related causes of QC failures. The QC program describes the type of QC tests performed, the parameters being evaluated, the frequency of each test, and who should perform each test. The QC program should include the daily, routine, and periodic QC tests to be performed by the NM technologists (refer to NM Technologist's Section of the QC manual).

### B. Equipment Purchase Specifications

NM equipment can be purchased in various manufacturer configurations that include a large variety of features and a wide range of hardware and software specifications. The quality of new equipment can be ensured through the use of purchase specifications. Purchase specifications also describe to manufacturers the type of equipment that is desired by the purchaser. Purchase specifications usually require manufacturers to provide detailed technical and performance specifications to the purchaser prior to the selection of equipment. These specifications are sometimes included as part of a formal document such as a request for proposal or request for information. The QMP's role is key in assisting the site with the necessary technical specifications required to meet the clinical imaging expectations. These manufacturer-provided specifications can be used to help determine the equipment to be purchased and also as a set of quantitative performance specifications to be compared with testing results and measurements with the NM equipment during acceptance testing. The purchase of new equipment should be made contingent on satisfactory performance that meets manufacturer's specifications during acceptance testing.

### C. Acceptance Testing

Acceptance testing applies to new equipment and is performed prior to routine clinical use. It should be performed by a QMP and consists of a series of specific tests that will determine if the performance of the new system meets the specifications provided by the manufacturer as listed in the equipment manual and related documentation. The approval of the purchase of the new equipment should be made contingent upon satisfactory performance during acceptance testing.

The description of acceptance testing procedures and limits is outside the scope of this document; however, testing performed during acceptance testing provides an opportunity to establish methods and baseline values that will serve as the basis for comparison for ongoing QC testing. For information and details regarding acceptance testing for specific NM equipment, please reference other documents, and/or inquire with the equipment manufacturer [1,2,4].

The QC program described in this manual is intended to test, verify, and document the consistency of performance after the system has been accepted and placed into operational use. Therefore, the QMP should consider using the results of these acceptance tests wherever possible as part of an initial set of baseline benchmarks for the ongoing QC program. The QMP may also consider performing additional tests (that is, tests that are not determining whether the scanner meets the manufacturer's specifications) that can serve as the initial testing of a condition that will be evaluated at annual testing; essentially performing the baseline tests that will be used as a comparison for the series of tests described in this QC manual.

### **D. Summary of Medical Physicist's Annual Survey**

The QMP should perform a series of tests annually to ensure the scanner is functioning properly and as designed in all respects while it is also used optimally. This manual recommends that prior to the QMP's annual physics survey, service engineers have performed preventive maintenance and/or other necessary calibrations to ensure that the equipment is working properly from a mechanical standpoint and that it performs optimally as far as QC and imaging. The following is an outline of the annual tests to be performed by the QMP:

#### **1. Physical Inspection and Mechanical Tests**

- a. Scanner Mechanical Inspection
  - i. Physical condition including collimator inspection
  - ii. Safety mechanisms and interlocks
  - iii. Gantry and table movements (translation, rotation, etc)
- b. Workstation Monitors for Acquisition/Processing of Images
  - i. Luminance measurement
  - ii. Luminance uniformity
  - iii. Resolution (analog monitor)

#### **2. Planar Gamma Camera Testing**

- a. Energy verification (peaking)
- b. Intrinsic flood field uniformity

- c. Extrinsic flood field uniformity
- d. Intrinsic off-peak flood field uniformity (recommended)
- e. Energy resolution
- f. Count rate performance
- g. System sensitivity
- h. Spatial resolution and spatial linearity (intrinsic and extrinsic)

### 3. SPECT Image Quality

- a. Spatial resolution
- b. Uniformity
- c. Contrast detectability
- d. Attenuation correction
- e. Artifact evaluation

### 4. Hybrid (SPECT-CT) Systems

- a. SPECT and CT image alignment (registration)
- b. CT dosimetry and CT image quality assessment
- c. CT-based attenuation correction

### 5. NM Support Equipment

- a. Dose calibrator
  - i. Geometry
  - ii. Constancy
  - iii. Linearity
  - iv. Accuracy
- b. Uptake probe and well counters
  - i. Energy calibration and high voltage
  - ii. Constancy
  - iii. Chi-square
  - iv. Minimum detectable activity (MDA)

## Medical Physicist's Annual Survey

The tests summarized in this manual may be performed using the methodologies described in the procedures. These are not the only methods that can be used but they present a series of tests that are reproducible and relatively easy to perform.

### A. Test Procedures

#### 1. Physical and Mechanical Tests

##### PURPOSE

To perform a physical inspection of the gamma camera system and ensure that it is in good mechanical condition and functions properly. This test is of great importance as it relates to the proper functioning of the equipment with implications not only for image quality but also for patient safety.

##### FREQUENCY

At acceptance testing, annually, and after relevant service

##### TEST PROCEDURE

1. Mechanical Components
  - a. Visually inspect the gamma camera for any apparent physical damage such as dents, bent or loose gantry panels or bed covers, etc.
  - b. Inspect the condition of air filters and verify they are free of dust and lint. This would apply to air filters that are visible externally and would not require covers to be removed.
  - c. Detector shielding: Visually inspect the external interface between the detector and the collimator for potential gaps that could lead to radiation leakage when imaging.
  - d. Test and verify that mechanical movements such as gantry rotation and detector translations are smooth and without problems. Verify the up/down, in/out movements of the imaging pallet are smooth and without problems, such as unusual noise or interrupted motion.
  - e. Verify that the angle indicators for the gantry position are accurately shown on the display (eg, at 90° and 180°).
  - f. Inspect all computer hardware associated with the gamma camera system and note their physical condition and operational status.
2. Collimators and Detector(s)
  - a. Visually inspect the collimators for any apparent physical damage such as dents and verify the collimator exchanging process works smoothly and without any problems. Ensure there is no excessive dust collected on the collimators.
  - b. Visually inspect the detector casing after removing the collimator for any damage such as dents or scratches.



3. Safety Interlocks
  - c. Identify and test the emergency stop switches (e-stops) or verify with the site that the safety interlocks were tested by the field service engineer during preventive maintenance.
  - d. Test the collision sensors on the collimator touchpads and verify that they are properly activated by pressing or touching the detector(s).
  - e. Visually inspect laser guardrails for any physical damage such as broken or cracked window glass that might compromise functionality.

**ACTION LIMITS AND  
REMIEDIATION**

Any observed issues and any problems encountered should be brought to the attention of the facility, and anything that requires intervention by the equipment's service engineering should be documented and reported. Any malfunction should be appropriately repaired, and any replacement of parts and components should take place as needed to ensure personnel and patient safety.

## 2. Acquisition and Processing Workstation Display Testing

<b>FREQUENCY</b>	At acceptance testing, annually, and after relevant service
<b>PURPOSE</b>	To ensure that images displayed on the acquisition and processing monitors of the gamma camera system show the entire range of gray shades produced by the system. This testing also checks the uniformity and resolution of the monitors. This testing does not refer to the persistence scope that might be part of the gamma camera.
<b>FREQUENCY</b>	This test must be performed annually. Additionally, it must be completed at the initiation of the QC program and whenever a significant change is made to the display monitors.
<b>REQUIRED EQUIPMENT</b>	<ul style="list-style-type: none"> <li>• AAPM TG-18 test pattern or Society of Motion Picture and Television Engineers (SMPTE) test pattern. These patterns should be compatible with the monitor bit depth and software display capability (eg, DICOM Part 10 or TIFF). Do not use a lossy-compressed format such as JPEG or PNG. In many cases, the camera manufacturer provides a scheme to load test patterns on the monitors—if so, use that method. Using AAPM TG-270 test patterns and recommendations is also acceptable.</li> <li>• Calibrated photometer with adequate precision, accuracy, and calibration to effectively measure luminance in the range 0.1 to 500 cd/m<sup>2</sup>.</li> </ul>
<b>TEST PROCEDURE</b>	<ol style="list-style-type: none"> <li>1. Display the TG-18 test pattern or SMPTE test pattern on the monitor. Note that the monitor should be positioned so that there is no glare from room lighting. Do not modify the window width/level by eye; doing so invalidates this procedure.</li> <li>2. Examine the pattern to confirm that the gray level display on the imaging console is subjectively correct.             <ol style="list-style-type: none"> <li>a. Review the line pair patterns in the center and at each of the corners.</li> <li>b. Review each black-white transition for sharpness.</li> <li>c. Examine areas of smooth gradations for evidence of “scalloping” (loss of bit depth) or geometric distortion.</li> <li>d. Examine the image for signs of spectral distortion (coloration)—the test patterns are pure grayscale images, and no colors should be rendered.</li> <li>e. Confirm that the 5% and 95% gray level patches are visible.</li> </ol> </li> </ol>

3. Adjust the window width/level to achieve pure black and use the photometer to measure the minimum monitor brightness at the center of the display.
4. Adjust the window width/level to achieve pure white and use the photometer to measure the maximum monitor brightness at the center and near all four corners of the display.

**DATA INTERPRETATION AND ANALYSIS**

**NOTE:** Manufacturer's specifications may also be used.

1. Visual Analysis
  - a. The visual impression should be an even progression of gray levels around the ring of gray level steps. All gray level steps in the ring of gray levels must be visibly distinct from adjacent steps.
  - b. The 5% patch must be visible in the 0/5% patch; the 95% patch must be visible in the 95/100% patch.
  - c. Ensure that the finest line pair pattern can be visualized in the center and at each of the four corners.
  - d. There must not be visible bleed-through in either direction of all black-white transitions. All high contrast borders must be straight, not jagged.
  - e. There must not be scalloping of the gray scale. There must not be geometric distortion in the image.
2. Photometric Analysis
  - f. The maximum luminance should be greater than or equal to 90 cd/m<sup>2</sup>, and minimum luminance should be less than 1 cd/m<sup>2</sup>.

Calculate the nonuniformity of the display luminance using the following equation:

$$\% \text{ difference} = 200 \times (L_{\max} - L_{\min}) / (L_{\max} + L_{\min})$$

in which  $L_{\max}$  and  $L_{\min}$  are the maximum and minimum measured luminance values of the five measurements made in Test Procedure step 4 above, respectively. The nonuniformity should not exceed 30% for CRT (cathode ray tube) displays and flat panel displays.

**ACTION LIMITS AND REMEDIATION**

If any of the Visual Analysis conditions are not met, do not adjust the display window width/level in an effort to correct the problem. Corrective action for the monitor is needed.

In many instances, other problems are caused by incorrect adjustment of the monitor's brightness and contrast. Excessive ambient lighting can aggravate this problem. Problems can also be caused by poor connections, which are easily remediated.

For subpar results in Photometric Analysis, perform the manufacturer's recommended procedure for monitor contrast and brightness adjustment. If there is any doubt about the correct procedure or if the brightness and contrast controls are not accessible, request that a service engineer make the adjustments.

### 3. Photopeak Energy Verification

**PURPOSE** To verify that the energy peak for the specific radionuclide is appropriately centered in the energy window width to ensure optimized acquisition of radioactive counts while excluding scatter that can degrade image quality.

**FREQUENCY** At acceptance testing for all radionuclides that will be used clinically for patient imaging and for QC testing, and annually or after relevant service for all radionuclides that are used for QC testing.

**PREPARATION** Prepare point sources of a small, concentrated volume with a proper amount of activity for the radionuclide to be tested. Point sources should be placed at a sufficient distance to irradiate the detector uniformly with deadtime not exceeding 10% (typically achieved with count rate less than 40,000 cps).

**TEST PROCEDURE** Examine the energy peak (keV) of the radionuclide to ensure it is centered within the energy window (Figure 4-1 below). For example, for Tc-99m, the photopeak should be verified near 140 keV. If Co-57 is used for QC, its photopeak centered near 122 keV should be also verified as part of this test. In many systems, this centering is performed automatically, but if not, it should be adjusted manually to be properly centered. The width of the energy window should be preset appropriately according to the QC or clinical protocols used (eg, at 15% or 20%). The energy peak should not deviate significantly from the physical photopeak(s) of the radionuclide. For dual-head or multi-head systems, the procedure should be performed for each detector and the comparison should be made to ensure their performance does not differ significantly.

**EVALUATION** The radionuclides tested along with their energy levels and window widths should be documented. Comparison should be performed with baseline or previous results. For dual-head or multi-head systems, the relative performance of the detectors should be compared.

**ACTION LIMITS AND REMEDIATION** A threshold of 2% difference from the physical photopeak is recommended for any of the comparisons performed. This would be approximately 3 keV for Tc-99m, but for older cameras the QMP might specify a slightly more lenient threshold. Any significant

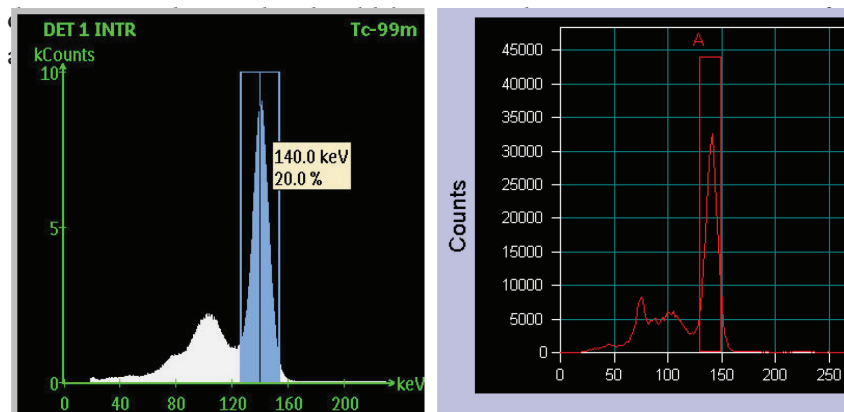


Figure 4-1. Energy verification (peaking) for Tc-99m at 140 keV shown for two different systems.

#### 4. Intrinsic Flood Field Uniformity

**PURPOSE** To evaluate the detector of the gamma camera for its ability to acquire a uniform image without significant variations in count density across the field of view (FOV) or artifacts, when exposed to a uniform flux of radiation without the collimator.

**FREQUENCY** At acceptance testing: Perform using Tc-99m and with any other radionuclides that will be used clinically with the system.

At annual physics survey: Perform using Tc-99m and optionally with any additional radionuclides used clinically or as deemed necessary by the QMP.

**PREPARATION** Prior to performing this test, check and record the date of the most recent uniformity calibration done on the system, typically using a high-count flood, such as 100M or 200M counts and with which radionuclide (usually Tc-99m or Co-57). Verify that the room background radiation level is very low prior to any intrinsic test and measurement.

**TEST PROCEDURE** The collimator should be removed from the detector and the gantry rotated toward the point source, which could be placed at a distance of 3 to 5 UFOV from the detector (in which the UFOV is defined as the longest detector dimension). The point source could be affixed on the wall or otherwise positioned so that the generated flux of radiation is centered on the detector(s) to be tested (Figure 4-2 below). The alignment of the point source position to be centered over the detector(s) can be assisted using a laser pointing device. The combination of the point source activity and the distance from the detector should provide a deadtime not exceeding 10% (typically achieved with a count rate less than 40,000 cps).

Acquire uniformity flood field images using at a minimum a 256 × 256 matrix for at least 30M counts. The matrix size and total number of counts will have to yield images of sufficient count density to be appropriately evaluated by the QMP or to meet manufacturer specifications for evaluation and quantitative analysis.



Figure 4-2. Two different detector configurations for intrinsic uniformity for dual-head gamma cameras. The point source must be at a distance of 3 to 5 UFOV. The system on the left acquires both detectors simultaneously, whereas the system on the right acquires one detector at a time.

**EVALUATION**

The flood images should be evaluated both visually and quantitatively. Visually inspect the acquired images for nonuniformities, such as artifacts, patterns, or photo-multiplier tube (PMT) visualization (faint or strong). Quantitative analysis should be performed to calculate the Integral Uniformity (IU) variation in the UFOV as well as the Central FOV (CFOV). This analysis should be performed using the manufacturer's available QC software, if possible; otherwise, the QMP may define a manual method for calculation of flood uniformity, which specifies matrix size, smoothing filter, and other relevant parameters. The IU can be obtained using the formula:

$$IU = \frac{\text{Maximum Pixel Value} - \text{Minimum Pixel Value}}{\text{Maximum Pixel Value} + \text{Minimum Pixel Value}} \times 100\%$$

The quantitative results and images should be recorded and included in the QMP annual physics survey report. For dual-head or multi-head systems, the relative performance of the detectors should be compared. The overall results should be compared with the baseline or the previous year's annual physics survey.

**ACTION LIMITS AND REMEDIATION**

Refer to the manufacturer's recommended acceptable levels of performance with respect to the IU of the UFOV and CFOV, respectively. In the absence of published manufacturer specifications or site-specific derived criteria, the QMP should apply reasonable action limits depending on the type of gamma camera, size of the detector, and intended clinical use.

Significant nonuniformities detected visually or quantitatively might require a new flood calibration to be performed and the system to be retested. Persistent issues should be reported to service engineering for appropriate calibrations or repairs as deemed necessary.

#### 5. Extrinsic (System) Flood Field Uniformity

**PURPOSE** To evaluate detector uniformity performance with collimator on, confirming that count density is appropriately uniform when exposed to a uniform flux of radiation. This test also allows for evaluation of artifacts and collimator defects.

**FREQUENCY** At acceptance testing and annual physics survey: Perform this test for all clinically used collimators.

**PREPARATION** Use a Co-57 sheet source and place it over the collimator to cover the entire imaging FOV. For dual-head gamma camera systems, the source can be elevated on risers so that it is placed in between the two detectors and the flood images can be acquired simultaneously for both detectors (Figure 4-3 below). The Co-57 sheet source should be of sufficient activity that it produces an adequate count rate (recommend greater than 10,000 cps). For new Co-57 sheet sources, caution should be exercised with regard to high-energy contaminants that can cause nonuniformity artifacts and affect the image quality. Photopeak energy verification for Co-57 extrinsically should be performed prior to acquiring counts. The appropriate radionuclide flood correction table should be selected for uniformity correction.

**TEST PROCEDURE** Perform the test using at a minimum a  $256 \times 256$  matrix and 10M total counts or use appropriate parameters for adequate count density depending on the size of the FOV of the gamma camera.

**EVALUATION** Display the image(s) and evaluate visually the extrinsic uniformity for areas of nonuniform count distribution, any type of artifacts, patterns such as PMTs, and collimator defects. Quantitative analysis should be performed to calculate the IU variation in the UFOV and CFOV for all images acquired. This analysis should be performed using the manufacturer's QC software, if available; otherwise, the QMP may define a manual method for calculation for flood uniformity, which specifies matrix size, smoothing filter, and other relevant parameters. For dual-head or multi-head systems, the relative performance of the detectors should be compared. The overall results should be compared with the baseline and the previous

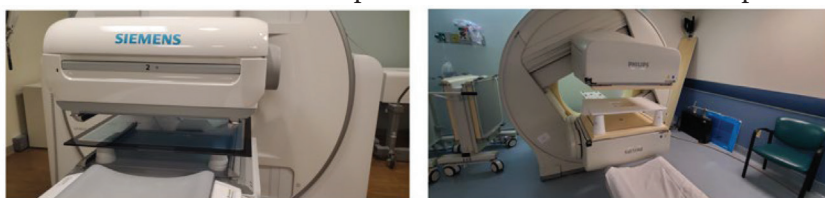


Figure 4-3. Setup for dual-detector simultaneous acquisition of extrinsic uniformity using a Co-57 sheet source for systems from two different manufacturers.



#### **ACTION LIMITS AND REMEDICATION**

The obtained images and quantitative results should be evaluated by the QMP for application of reasonable action limits depending on the type of gamma camera, size of the detector, and intended clinical use. Significant nonuniformities detected visually or quantitatively might require a new flood calibration to be performed and the system to be retested. If a concerning artifact is detected, the system might have to be tested intrinsically to isolate the source of the problem (eg, if caused by a collimator defect). Persistent issues should be reported to service engineering for appropriate calibrations or repairs as deemed necessary.

### 6. Intrinsic Off-Peak Flood Field Imaging (Recommended)

**PURPOSE** This test evaluates the gamma camera detectors for crystal hydration, presence of “measles,” PMT performance (gain, light collection) imbalance, or PMT decoupling from the crystal.

**FREQUENCY** At acceptance testing and annually (recommended)

**PREPARATION** With the collimator(s) removed from the detectors, the gantry is oriented similarly to the acquisition of an Intrinsic Flood Field Uniformity. This test should be performed using a point source with a small amount of Tc-99m activity, such as 500  $\mu$ Ci (18.5 MBq), at a distance of 3 to 5 UFOV centered over the detectors. Similarly, Tl-201 could be used with its lower energy photons (approximately 70 keV) and could be more sensitive than Tc-99m for the evaluation of crystal hydration.

**TEST PROCEDURE** This test can be more effective by turning off certain detector corrections, such as uniformity, linearity, and energy, but this might require assistance from service engineering for some systems. Separate flood images should be acquired for each detector in a  $256 \times 256$  or higher matrix for at least 10M counts at energy window settings that are off-peak on either side of the photopeak. For example, if Tc-99m is used, off peaks could be as follows: (a) “low” at 126 keV (–10% energy shift) using a 15% or 20% window width and (b) “high” at 154 keV (+10% energy shift) using a 15% or 20% window width (Figure 4-4 below). If Tl-201 is used, the off-peak windows should be similarly set with respect to its lower energy x-ray photopeak around 70 keV. Some gamma camera systems can acquire both images of low off-peak and high off-peak energy windows simultaneously.

#### EVALUATION

Inspect the acquired off-peak flood images for each detector, preferably by having the “low” and “high” in a two-view side-by-side display format. The images should appear “mirrored” in

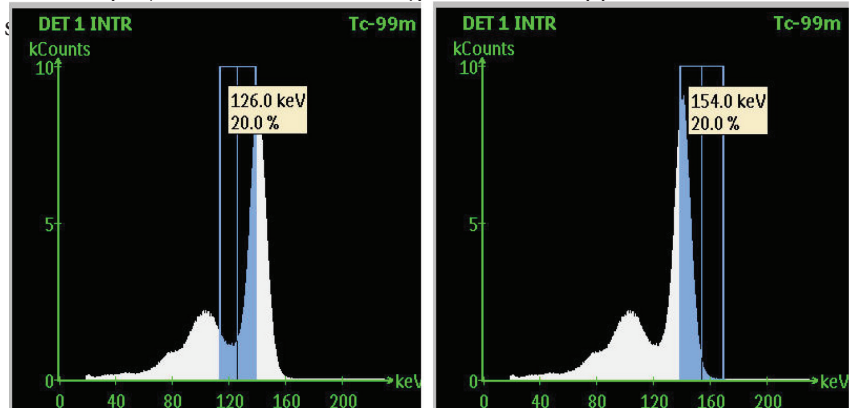


Figure 4-4. Off-peak energy window settings (–10% energy shift left and +10% energy shift right) for Tc-99m acquisitions.

as a “hot” versus “cold” pattern, respectively (Figure 4-5 below). If any PMT has significantly different intensity from other PMTs, this could signify possible tube decoupling from the detector. The presence of distinct spots of nonuniformity, ie, measles, are indicative of crystal hydration. These spots should be brighter in the “low” image and cold or low intensity in the “high” image.

#### **ACTION LIMITS AND REMEDIATION**

Any suspected crystal hydration and/or measles should be reported to service engineering for appropriate evaluation and possible crystal replacement if deemed necessary. Any distinct PMT pattern or deviation should be reported to service engineering for evaluation and possible recoupling and/or PMT replacement as deemed necessary.

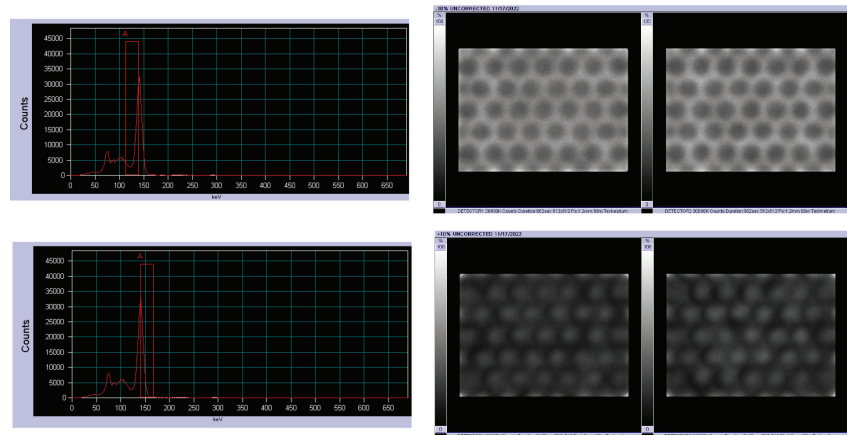


Figure 4-5. Off-peak acquisitions with Tc-99m for a dual-head gamma camera: –10% energy window on the left, and +10% energy window on the right, with resulting images.

## 7. Energy Resolution

**PURPOSE** This test measures the energy resolution of the detector of the gamma camera for a particular radionuclide and expresses it as a percentage of the full-width half-maximum (FWHM) of the photopeak energy. Energy resolution determines the efficiency by which the gamma camera can discriminate energies and reject scatter; therefore, image quality can be affected. Deterioration of the energy resolution can signify issues with the crystal or with the detector calibrations. The method described in this procedure is one approach for measuring energy resolution, but other methods can be also used [4].

**FREQUENCY** At acceptance testing and annually, measure the energy resolution for Tc-99m.

**PREPARATION** This test is performed intrinsically using a point source with a small amount of activity of Tc-99m at a sufficient distance to irradiate the detector uniformly and to generate an adequate count rate. The setup is similar to the one for the intrinsic flood field uniformity. The energy spectrum is acquired, and the energy resolution is measured separately for each detector.

**TEST PROCEDURE** If there is manufacturer's specialized software available for the acquisition of the energy spectrum and calculation of the percent energy resolution at FWHM, it should be followed as per the system's user manual. The methodology to be followed will depend on the tools available with the system.

This can be done by multiple methods. Some systems have QC software that will perform the calculations for energy resolution. Another way is to export the energy spectrum to be analyzed in Excel. If the spectrum is displayed and can be traced, the counts and keV values corresponding to the peak and FWHM on each side of the curve can be used to calculate the percent energy resolution at FWHM.

If the system does not have a method available, the testing can be performed by setting a narrow energy window, such as 2% or 3 keV, that will be shifted from the low-energy end to the high-energy end of the pulse-height spectrum for multiple acquisitions (eg, from 120 to 150 keV in small keV increments and to include the 140 keV photopeak to provide sufficient data points for plotting the spectrum graph and calculating the FWHM). Each acquisition should be for a preset time to collect sufficient counts (eg, 10 seconds).

**EVALUATION** Calculate the percent energy resolution at FWHM for Tc-99m, using the formula below, as illustrated in [Figure 4-6](#):

$$\% \text{ Energy Resolution} = \frac{\text{High Energy at FWHM} - \text{Low Energy at FWHM}}{140.5 \text{ keV}} \times 100\%$$

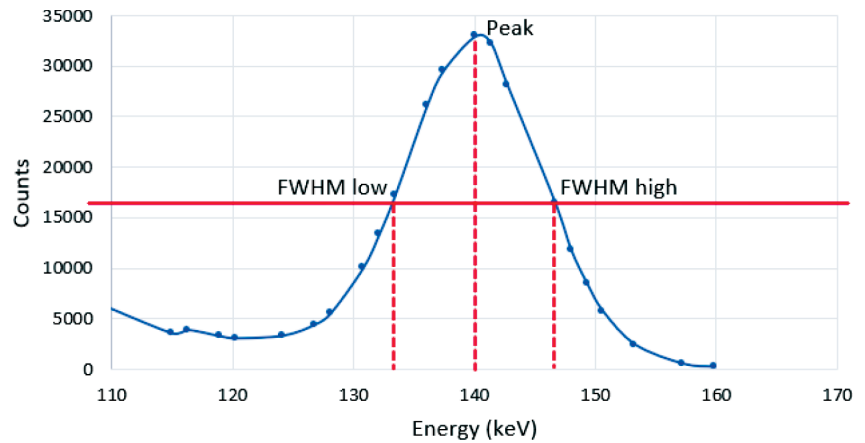


Figure 4-6. Visualization of energy resolution at FWHM for Tc-99m.

**ACTION LIMITS AND REMEDIATION**

The energy resolution for a conventional NaI(Tl) gamma camera detector should be less than 11%. The manufacturer's specification is typically less than 11% but requires a precise measurement according to the NEMA protocol, which is not usually accessible to the physicist for annual testing. The obtained value should be compared with the baseline value from acceptance testing and also with the values from previous annual tests. Similarly, for multi-head systems, the value should be compared for all the detectors. Large deviations in the results should be reported and service should be requested for possible calibration or repair.

## 8. Count Rate Performance

<b>PURPOSE</b>	This test measures the maximum achievable count rate performance of the detector(s) of the gamma camera for Tc-99m in a paralyzable system. This test is not applicable for some pixelated detectors. The method described in this procedure is one way to perform this test, but additional methods are described in other publications [1,4].
<b>FREQUENCY</b>	At acceptance testing and annually, measure the maximum count rate performance of the gamma camera detector using Tc-99m.
<b>PREPARATION</b>	This test should be performed intrinsically with a point source of Tc-99m in the range of 0.5 to 1 mCi (18.5 to 37 MBq). The detector should be peaked with a 20% window centered over the photopeak at a low-count rate (less than 20 kcps) and not readjusted during testing.
<b>TEST PROCEDURE</b>	Once the collimators have been removed, the source can be placed on a pole or cart at a height equal to the center of the UFOV (Figure 4-7 below). Find the starting location where the count rate is approximately 20 kcps. The source should be slowly moved closer to the exposed crystal. Continually monitor the count rate on the p-scope. The count rate should increase to the maximum count until the system becomes paralyzed and the count rate begins to decrease. Once this is achieved, the maximum count rate should be documented.
<b>ACTION LIMITS AND REMEDIATION</b>	Most conventional NaI(Tl) gamma camera detectors can achieve count rates ranging from 150 to 400 kcps. The obtained value should be compared with the baseline value from acceptance testing and also with the values from previous annual tests. The difference in the comparisons should be less than 5%. Similarly, for multi-head systems, the value should be compared with all the detectors and there should not be a difference of more than 5%. Large deviations in the results and/or other related concerns of the QMP should be reported, and service engineering should be requested as needed.



Figure 4-7. Setup for count rate measurement with point source attached to a tripod (left) or pole (right) placed at a height centered with the detector.

## 9. Spatial Resolution and Spatial Linearity

**PURPOSE** To evaluate the spatial resolution and spatial linearity of the detector and the imaging system. Spatial resolution is measured (in mm) at the FWHM of the line-spread-function (LSF), which is generated by plotting the count profile of an imaged-line source. Spatial resolution can also be measured quantitatively and/or qualitatively using a four-quadrant bar phantom. Spatial linearity can be evaluated by qualitative analysis to verify that the line source or bars on the four-quadrant bar phantom appear straight with no curves or distortions. For digital detector or pixelated detector cameras, the QMP should decide if spatial resolution and linearity are relevant for testing the systems. Spatial resolution and spatial linearity testing can be performed either intrinsically or extrinsically, and this procedure describes methods how this could be accomplished.

**FREQUENCY** At acceptance testing: Perform using intrinsic method with Tc-99m.

Annually: Perform intrinsically or extrinsically

### Intrinsic Methods

**TEST PROCEDURE** This can be performed by either using a four-quadrant bar phantom or a slit phantom.

### **FOUR-QUADRANT BAR PHANTOM**

1. If the bar phantom is to be used for annual testing, a baseline image should also be obtained at acceptance testing for subsequent comparisons.
2. The four-quadrant bar phantom should have appropriate spacing of the bar widths to be able to effectively test the system. This manual recommends using a bar phantom provided by the manufacturer of the gamma camera. The quadrant with the smallest bars should have a spacing of approximately half of the expected intrinsic spatial resolution. The ACR accreditation guidelines recommend using a bar phantom with the smallest bars between 2 and 3 mm (see the article [ACR Phantom Testing: Nuclear Medicine](#)). Qualitative evaluation of the four-quadrant bar phantom consists of identifying visually the quadrant with the smallest bars resolved in the image. The four-quadrant bar phantom could be used for quantitative evaluation and measurement of the intrinsic spatial resolution using the method described by Hander [4,7,8,9], which includes a specific set of parameters for acquisition that are different from what is described in this procedure. Remove the collimator and place the four-quadrant bar phantom directly on the detector crystal. Because of the fragility of the crystal, the phantom should be placed with additional care. A protective layer between the crystal and phantom that consists of 2 to 3 mm of cardboard or acrylic can be used.



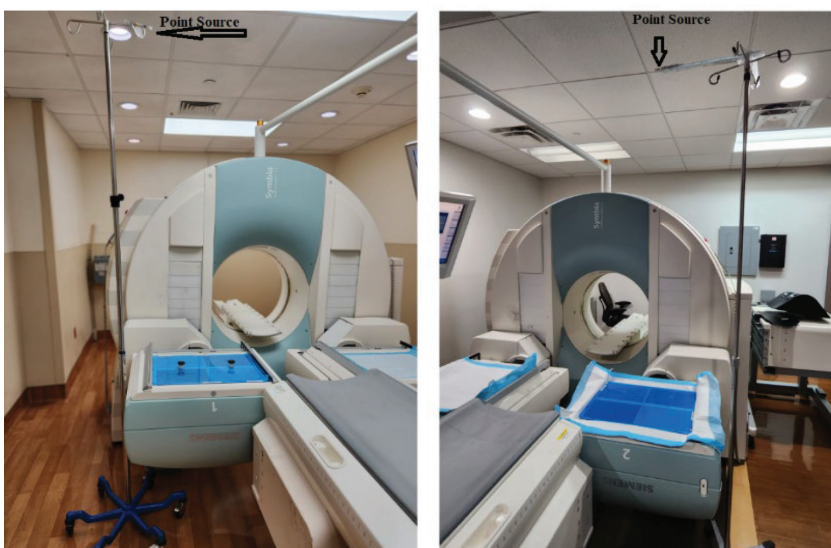


Figure 4-8. Example of a detector configuration for intrinsic bar phantom acquisition with the point source hanging on an IV pole, centered over the acquisition field of view.

3. A point source with 0.5 to 5 mCi (18.5 to 185 MBq) of Tc-99m should be placed at a distance of 3 to 5 UFOV from the face of the crystal (Figure 4-8 above). The count rate should be approximately 25 kcps.
4. The acquisition should be performed in a  $512 \times 512$  matrix for at least 5M counts.

#### FOUR-QUADRANT BAR PHANTOM EVALUATION

A qualitative assessment should be performed to determine the smallest distinguishable bar size. For intrinsic bars with Tc-99m, 2.9-mm bars or smaller should be resolved. However, the QMP should determine if stricter or more exact criteria should be considered based on the performance of the system at baseline measurement. The bar width of the resolved quadrant should be noted in the report. For dual-head or multi-head systems, compare the findings between the detectors and compare also with baseline or previous year's reported results.

A qualitative visual assessment should be performed for spatial linearity. The bar patterns should be straight with no bending or patterned distortions, such as curved lines or waves.

Quantitative measurement of the intrinsic spatial resolution can be obtained using Hander's method [4,7,8,9].

#### SLIT PHANTOM

1. Remove the collimator and place a slit phantom directly on the detector crystal. Because of the fragility of the crystal, the phantom should be placed with additional care. A protective layer between the crystal and phantom that consists of 2 to 3 mm of cardboard or acrylic can be used.



2. This manual recommends that the slit phantom follow the description in NEMA NU 1-2018. The measurements include 3 mm of lead with a slit width of 1 mm and 30 mm distance between the slits. The phantom should cover the entire UFOV. If it is smaller than the UFOV, additional lead strips should cover the exposed crystal.
3. A point source with 5 to 10 mCi (185 to 370 MBq) of Tc-99m should be placed at a distance of 3 to 5 UFOV from the face of the crystal.
4. Appropriate zoom and matrix sizes should be determined so that pixel size is less than 0.2 FWHM with a minimum of 250 counts per pixel.

### SLIT PHANTOM EVALUATION

A wide-line profile should be drawn perpendicular to the slit direction to determine the FWHM. This should be evaluated in both the X and Y directions on each detector. Typical values should be between 3- and 4-mm FWHM. However, the QMP should determine if stricter or more exact criteria should be considered based on the performance of the system at baseline measurement.

A qualitative visual assessment should be performed for linearity. The lines of the slits should all appear straight with no waves or breaks.

### ACTION LIMITS AND REMEDIATION

If the resolution has deteriorated from previous years or falls outside of the expected value range, then service must correct the issue. If nonlinearities are visualized, this is typically due to an old linearity correction. Linearity correction and uniformity corrections might need to be performed. Service is required to address this issue.

#### Extrinsic Methods

This can be performed using a four-quadrant bar phantom and a Co-57 sheet source. Other methods, such as imaging a line source suspended in air at a specific distance from the collimator, could also be used and they are described elsewhere [1,4].

### TEST PROCEDURE

Place the four-quadrant bar phantom on the face of the detector with a low-energy parallel-hole collimator on. Place a Co-57 sheet source over the bar phantom ([Figure 4-9](#)). Acquire using at least a  $512 \times 512$  matrix and a minimum of 5M counts. Two sets of images per detector should be at least acquired by rotating the bar phantom either  $90^\circ$  or  $180^\circ$  to image the bars of the finest width in at least two different quadrants of the detector.

### EVALUATION

A qualitative assessment should be performed to determine the smallest distinguishable bar size. For extrinsic bars using Co-57 and LEHR collimators, the 3.4-mm bars or smaller should be resolved. However, the QMP might specify other appropriate criteria based on the scanner

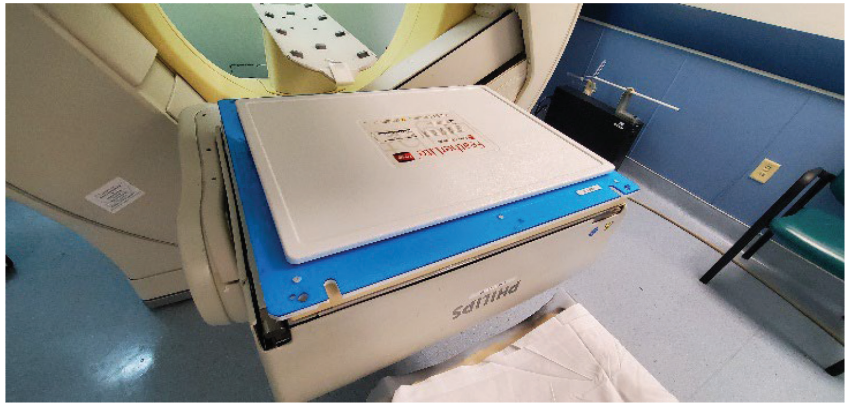


Figure 4-9. Extrinsic spatial resolution setup using the four-quadrant bar phantom and LEHR collimator.

and the collimators used. For dual-head systems, compare the findings between the detectors and compare also with baseline or previous year's reported results.

A qualitative visual assessment should be performed for spatial linearity. The bar patterns should be straight with no bending or patterned distortions, such as curved lines or waves.

#### **ACTION LIMITS AND REMEDIATION**

If the resolution has deteriorated from baseline or previous years or falls outside of the expected value range, then service must correct the issue. If nonlinearities are visualized, this is typically due to an old linearity correction. Linearity correction and uniformity corrections must be performed, and service would be required to address this issue.

#### **Extrinsic Planar Spatial Resolution Using the ACR Phantom**

As an alternative method of testing extrinsic spatial resolution, the ACR Phantom could be used. This test can be performed optionally at acceptance testing to create baseline images for subsequent comparisons with annual testing or when required for submission. This test provides a simple qualitative assessment of the ability of the system to resolve the cold rods of the ACR Phantom in planar mode. ***This test cannot be used to evaluate spatial linearity.*** For digital detector or pixelated detector cameras, the QMP should decide if this test is applicable for evaluating the extrinsic spatial resolution.

#### **FREQUENCY**

At acceptance testing and annual physics survey: This test should be performed with the low-energy parallel-hole collimator most commonly used for SPECT imaging.

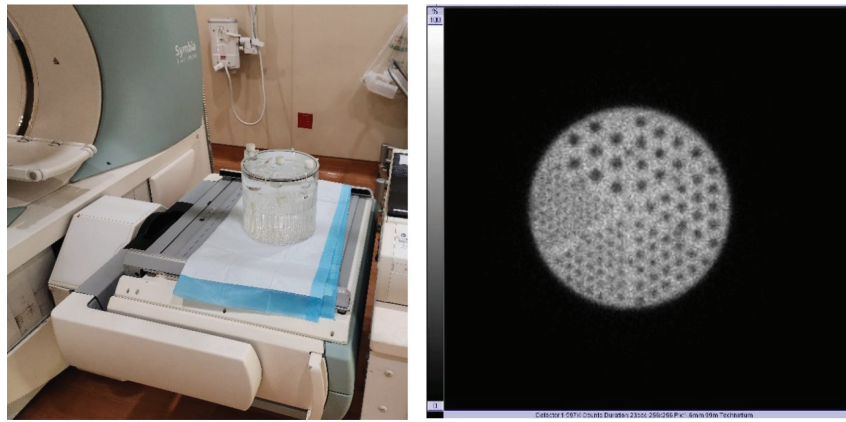


Figure 4-10. Setup for extrinsic spatial resolution test using the ACR Phantom (left) and obtained image (right) using an LEHR parallel-hole collimator.

### TEST PROCEDURE

Place the appropriate ACR Phantom centered in the FOV with the flat bottom of the phantom on the rods side sitting up and centered on the face of the low-energy parallel-hole collimator (Figure 4-10 above). Acquire a planar image for each detector for a total 600,000 counts in a  $256 \times 256$  matrix.

Instructions for filling up the phantom with Tc-99m activity are provided in the ACR NM testing document [ACR Phantom Testing: Nuclear Medicine](#).

### EVALUATION

Inspect the acquired images and identify the sector of the smallest rods that are resolvable. The 7.9-mm rods should be resolved with high contrast when using a LEHR collimator. The QMP might specify other appropriate criteria depending on the expected performance of the scanner and collimator. Evaluate also for possible artifacts such as areas within a sector of rods with variation in spatial resolution, such as increased blurriness. For dual-head or multi-head systems, compare the images for each detector to ensure that the performance is comparable. Record the results and note the collimator used to allow comparison with baseline or previous year's annual images and identify differences in terms of performance degradation.

### ACTION LIMITS AND REMEDIATION

If there is significant deterioration of results compared with baseline and previous annuals, the issue should be reported to service engineering for evaluation and appropriate calibrations and corrective action as needed.

### 10. Extrinsic Planar Sensitivity

**PURPOSE** To measure the planar sensitivity of a gamma camera detector with a collimator on in units of cpm/ $\mu$ Ci (or cps/Bq) for a radioactive source of known amount of activity placed within the detector's FOV.

**FREQUENCY** At acceptance testing, perform this test using Tc-99m and the low-energy parallel-hole collimator most commonly used clinically. Additionally, this test can be optionally performed for other collimators, such as medium and high energy with radionuclides of corresponding energy that are in clinical use at the site.

Annually perform this test using the low-energy collimator most commonly used clinically by the site, using Tc-99m.

**PREPARATION** A source with a known amount of Tc-99m between 0.5- and 1-mCi (18.5- and 37-MBq) solution should be prepared. The net activity and time should be recorded. The radioactive source could be a disc source or a 5- to 10-cc syringe (Figure 4-11 below). The consistency of this setup is very important for reproducibility of the results between benchmarking at acceptance testing and subsequent annual tests (eg, NEMA specifies reporting the sensitivity at a distance of 10 cm from the detector).

**TEST PROCEDURE** This test should be performed under conditions of low attenuation and low scatter. The setup of the source should be maintained consistent for each measurement and from year to year for accurate comparisons. This must include the source to detector distance. The source can be placed on the collimator for parallel-hole collimators. A distance of 10 cm should be used for nonparallel-hole collimators.

First acquire a background image without the source in the FOV and then acquire an image with the source in the FOV. All images should be acquired for the same time duration (eg, for 1 minute). The choice of matrix size does not affect the measurements but should remain consistent each year. Time of each acquisition for each image should be recorded to decay correct the activity.

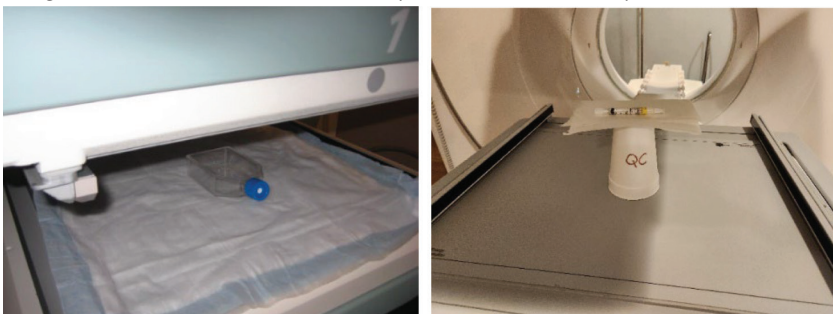


Figure 4-11. Two different radioactive source setups for measuring sensitivity with a parallel-hole collimator: Acquisition setup for the top detector (left) and the bottom detector (right).

#### **IMAGE ANALYSIS**

The total counts in the background and source images should be obtained. If a region of interest (ROI) is drawn, it should include the entire FOV, not just drawn over the source. The net activity should be decay corrected from the initial time it was prepared until the time of acquisition. The sensitivity is calculated as net cpm/ $\mu$ Ci (or cps/Bq).

#### **EVALUATION**

The results should be compared with the baseline or previous year's value to ensure that there is no deterioration of performance. For multi-head systems, compare the calculated result between the detectors and ensure it is within a 5% difference.

#### **ACTION LIMITS AND REMEDIATION**

The QMP should determine the acceptance value for this test obtained with the same technique used when creating the baseline results and by considering the manufacturer specifications. If the calculated planar sensitivity at annual testing differs significantly (greater than 5%) from the acceptance value set by the QMP, the problem should be investigated to determine any appropriate follow up, such as reporting to service engineering for corrective action.

### 11. SPECT Image Quality

**PURPOSE** To evaluate the SPECT system using an ACR-approved phantom for tomographic spatial resolution, SPECT uniformity, contrast detectability, attenuation correction, and artifacts. The radionuclide used should be Tc-99m. This test can be acquired in SPECT-CT mode for a hybrid system, and the SPECT reconstructed images could be used in conjunction with the CT images for test 12. Image Alignment (Registration).

**FREQUENCY** At acceptance testing to establish baseline performance for subsequent comparisons, and annually.

**PREPARATION** Instructions for preparing the phantom, imaging parameters and methodology, as well as reconstruction and image analysis, can be found in the ACR guidelines for imaging the ACR Phantom ([ACR Phantom Testing: Nuclear Medicine](#)).

**EVALUATION**

a. Uniformity

Inspect the reconstructed slices of the entire phantom with particular emphasis on the uniformity section for ring artifacts and other areas of nonuniform count density. The presence of rings should be classified as mild (faint) or strong (significant) by comparing them to background (noise). Faint artifacts in a single slice might not be affecting the images clinically, whereas strong artifacts in a single or multiple slices could impact the quality of clinical images and should be considered as a serious issue. Attenuation artifacts may be due to under- or overcorrection for attenuation. If focal areas of high or low count density are identified, they should be noted and characterized in terms of size and location.

b. Spatial Resolution

The smallest diameter cold rods sector of the reconstructed slices should be identified and recorded. A sector with cold rods is considered as identified when the outer row of the rods is clearly visualized. The contrast, whether low or high, of the identified cold rods should also be recorded. This should be determined from the composite image of the rod slices (thickness of 3 to 4 cm), which will provide better visualization. At a minimum, the 11.1-mm rod sector should be resolved. The collimators used, whether LEHR or general purpose, should also be recorded.

c. Contrast Detectability

The smallest-size sphere resolved should be identified and recorded, and the corresponding contrast should be mentioned with respect to the background. The 19.1-mm and larger spheres should be resolved with high contrast to grade as satisfactory. The collimators used, whether LEHR or low-energy general purpose, should also be recorded. Optionally, the sphere contrast for those spheres that are resolved could be calculated quantitatively by placing ROIs and obtaining the mean pixel count values, as described by AAPM Task Group 177 [4].



**ACTION LIMITS AND REMEDIATION**

If significant ring artifacts are observed in 1 or more slices that are considered to affect clinical imaging, then the system should not be used clinically for SPECT imaging until appropriate calibrations or repairs are performed. This problem could be due to nonuniformities, nonlinearities, and/or other detector issues. The QMP could determine if the system could still be used for planar imaging while remediation for the detected SPECT issues is pending.

If the observed spatial resolution and/or contrast detectability are not satisfactory or they remain unsatisfactory after the phantom test has been repeated for verification, the system should be serviced. Evaluation of the images should also include a comparison with baseline or previous years' test results.

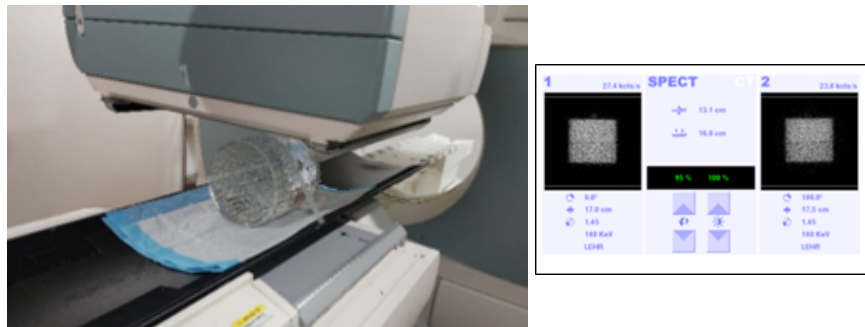


Figure 4-12. Positioning the ACR Phantom on a dual-head SPECT camera.

## 12. SPECT-CT Image Alignment (Registration)

**PURPOSE** To ensure registration of coordinate systems for SPECT and CT images sets that comprise a hybrid image data set. This is important for accurate CT-based attenuation correction of the SPECT images and for the display of properly aligned SPECT and CT images for clinical interpretation.

**FREQUENCY** This test must be performed annually. Additionally, it must be completed at the initiation of the QC program and following major repairs that involve separation of the SPECT and CT gantries.

**REQUIRED EQUIPMENT**

1. ACR SPECT Phantom—This test can use images acquired for test 11. SPECT Image Quality.
2. 3-D imaging workstation capable of either fused SPECT-CT or simultaneous SPECT and CT display with linked cursors. (Note: Software must be capable of display in coronal or sagittal planes as well as conventional axial slice display. If the latter is not met, then multiplanar reformats will need to be generated on the scanner console).

**TEST PROCEDURE**

1. Acquire a SPECT-CT study using the ACR Phantom and a clinical SPECT-CT protocol. If the study for SPECT Image Quality test (procedure 11 above) was acquired using SPECT-CT, the data can be used for this test.
2. Load a central transaxial slice of the SPECT and CT data onto the workstation display.
3. Confirm that images are registered horizontally and vertically. If an offset is visible, measure the extent using workstation measurement tools.
4. Either switch views to display data in coronal or sagittal views or load the coronal or sagittal multiplanar reformats produced by the scanner.
5. Measure the registration error along the z axis.

**EVALUATION (DATA INTERPRETATION AND ANALYSIS)**

**NOTE:** Manufacturer's specifications may also be used.

Misregistration between SPECT and CT coordinates is assessed as the displacement seen along the three principal axes. Note that this is not a full quantitative assessment of misregistration because rotation is not considered.



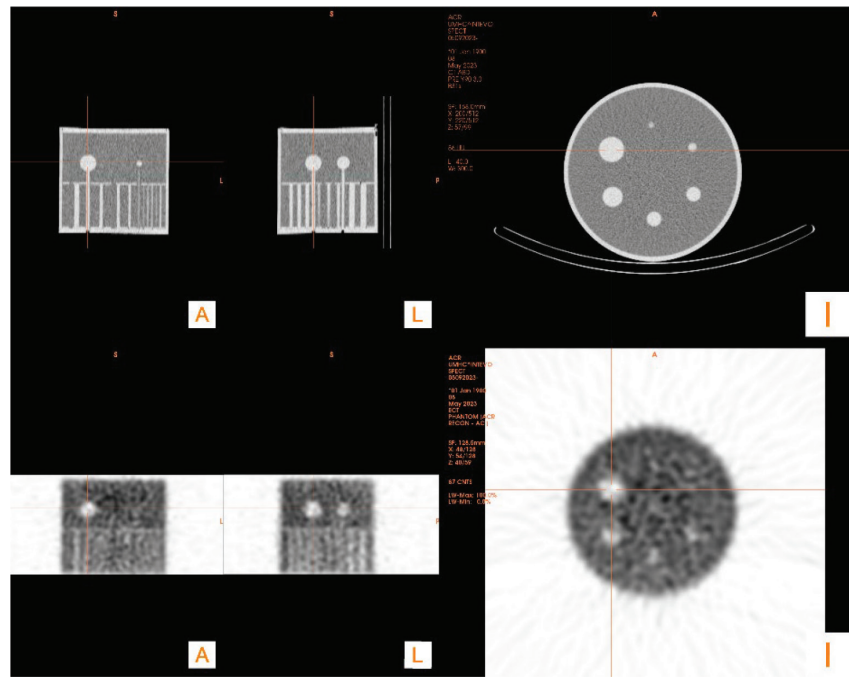


Figure 4-13. SPECT-CT images of the ACR Phantom acquired and reconstructed to test image registration. Software for fused display and triangulation tools can be very useful in testing image alignment.

**ACTION LIMITS AND REMEDIATION**

Misregistration between SPECT and CT data should be less than 5 mm along each of the principal axes. Misregistration greater than this is likely to affect clinical interpretation. If the misregistration exceeds 5 mm, it should be reported to service engineering for appropriate corrective action. Sites performing clinical dosimetry calculations should consider different phantoms that would allow more precise evaluation of the misregistration.

#### 13. CT Subsystem Dosimetry and Image Quality

**PURPOSE** Because performance and image quality in a SPECT-CT system depend also on the performance of the CT subsystem, this manual recommends that the QMP verifies and ensures appropriate CT function and performance. Emphasis should be placed on possible CT artifacts as well as the accuracy of the CT numbers, as this could affect the accuracy of CT-based attenuation correction of SPECT images. Image quality attributes that should be checked include CT number accuracy, CT noise and resolution, and image uniformity.

**FREQUENCY** At acceptance testing: verify that the measurements meet the manufacturer's specifications and/or published recommendations. The results will be used to create baseline criteria for subsequent annual surveys.

Annually, verify that the measurements meet the manufacturer's specifications and published reports and that there is no significant deviation when compared with prior annual surveys or with baseline criteria obtained at acceptance testing.

**TEST PROCEDURE** 1. Diagnostic CT Usage:

If the CT subsystem is used for diagnostic CT imaging, then the ACR guidelines for CT QC [14] should be followed for appropriate complete CT testing. The methodologies of how these CT tests should be performed are described elsewhere (see [ACR CT QC Manual](#) [14]).

2. Nondiagnostic CT Usage:

If the CT subsystem is used only for CT-based attenuation correction of SPECT images and morphological localization through image fusion of SPECT and CT, then the following subset of CT tests are recommended as part of the annual QC:

- Low-Contrast Performance
- CT Number Accuracy
- Artifact Evaluation
- CT Number Uniformity
- CT dose measurements

It is possible that the manufacturer-recommended QC procedures for the CT subsystem satisfy the aforementioned QC tests.

**NOTE:** Because of the variety of CT models in SPECT-CT systems, including nonconventional configurations, some of the CT criteria might have to be different (eg, the Low-Contrast Performance) or they might have to be more relaxed (eg, the CT numbers).

#### **EVALUATION, ACTION LIMITS, AND REMEDIATION**

Test results should be documented and reported as part of the SPECT-CT evaluation. Any significant deviations in the measurements from previous year's results or other acceptable limit criteria applicable to the specific test and CT equipment, and/or, any artifacts observed in the phantom imaging should be addressed with service engineering for appropriate calibrations and/or repairs as necessary.

## B. Dose Calibrators

Dose calibrators measure and confirm activity prior to patient injection, so QC of these devices is critical.

### 1. Dose Calibrator Geometry

<b>PURPOSE</b>	To verify proper performance and consistent reading of the dose calibrator with different source sizes such as vials and syringes.
<b>FREQUENCY</b>	At installation and after major repair.
<b>REQUIRED EQUIPMENT</b>	Glass vials or syringes in all sizes that are used clinically, depending on method chosen. Saline.
<b>TEST PROCEDURE (VIAL METHOD)</b>	<ol style="list-style-type: none"> <li>1. Perform background check.</li> <li>2. Add 2 to 5 mCi (74 to 185 MBq) of Tc-99m in 1 mL to a 10-cc glass vial. Record the reading.</li> <li>3. Add 1 mL of normal saline to the vial. Record the reading.</li> <li>4. Continue to add 1 mL of normal saline and take the reading until 8 mL have been added (eight readings).</li> </ol>
<b>TEST PROCEDURE (SYRINGE METHOD)</b>	<ol style="list-style-type: none"> <li>1. Perform background check.</li> <li>2. Add 1 to 2 mCi (37 to 74 MBq) of Tc-99m in 0.5 mL to a 3-mL syringe. Record the reading.</li> <li>3. Add 0.5 mL of normal saline to the syringe. Record the reading.</li> <li>4. Continue to add 0.5 mL of normal saline and take the reading until 3 mL has been added.</li> <li>5. This should be performed for all syringe sizes used routinely in the clinic. Note: for 1-mL syringes, saline should be added in 0.2-mL increments up to 1 mL. For larger size syringes, saline should be added in 1-mL increments.</li> </ol>
<b>EVALUATION</b>	Choose one reading as the reference volume activity. Calculate the difference in the readings for each volume compared with the reference activity.
<b>ACTION LIMITS AND REMEDICATION</b>	The percent deviation of the measured activity to the reference volume activity must be within $\pm 10\%$ . If the deviation is greater than $\pm 10\%$ , mathematically corrected dosage reading can be applied, or the unit can be serviced.

## 2. Dose Calibrator Constancy

<b>PURPOSE</b>	To verify proper performance and consistent reading of the dose calibrator on multiple radionuclide settings.
<b>FREQUENCY</b>	This is a technologist's test performed each day of use (see Technologist QC Section of this manual). This is performed at installation, and action limits should be defined by the QMP. The following testing procedure is included for reference.
<b>REQUIRED EQUIPMENT</b>	A NIST traceable, long-lived standard such as Cs-137, Co-57, or Na-22 to be used as the test source.
<b>TEST PROCEDURE</b>	<ol style="list-style-type: none"><li>1. Perform background check.</li><li>2. Place the test source into the chamber of the dose calibrator and select the proper radionuclide channel on the dose calibrator.</li><li>3. Measure the source and record the reading.</li><li>4. Leave the source in the chamber and select the channels of commonly used radionuclides.</li><li>5. Record the readings.</li></ol>
<b>EVALUATION</b>	Compare readings with previous results.
<b>ACTION LIMITS AND REMEDIATION</b>	The percent deviation of the measured activity to the previous results must be within $\pm 10\%$ . If the deviation is greater than $\pm 10\%$ , the instrument should be taken out of use and must be serviced.

#### 3. Dose Calibrator Linearity

**PURPOSE** To verify the dose calibrator has a linear response from the highest activity level used clinically to less than 30  $\mu\text{Ci}$  (1.11 MBq).

**FREQUENCY** Testing is to be performed at installation, annually (recommended quarterly) basis, and after major repair. Please check with local state or Nuclear Regulatory Commission applicable regulations regarding the frequency of this test.

**REQUIRED EQUIPMENT** Tc-99m source. For the attenuator tube method, use commercially available linearity tubes consisting of different thicknesses of lead, designed to mimic the decay of a radioactive source.

**TEST PROCEDURE (DECAY METHOD)**

1. A source of Tc-99m should be assayed in the dose calibrator. The source activity should be at least as large as the maximum activity assayed for administration.

2. Record the activity, time, and date. This will be considered time 0.

3. Reassay the source over multiple time points throughout the day, such as every 4 hours. Record the activity, time, and date of each assay.

4. Continue taking measurements until the source has decayed below 30  $\mu\text{Ci}$  (1.11 MBq). Depending on the source activity, this can take several days.

5. Using all activity-time data points, find the best fit for the decay curve.

6. Compare the expected readings with the measured readings.

7. All readings should be within  $\pm 10\%$ .

**TEST PROCEDURE (ATTENUATOR TUBE METHOD)**

1. Remove the "dipper" from the chamber and place the first set of tubes in the chamber. The source activity should be greater than the highest activity administered to patients.

2. Measure the source and record the reading.

3. Tubes should be added/removed in accordance with the manufacturer's instructions.

4. Continue until the source measures below 30  $\mu\text{Ci}$  (1.11 MBq).

5. Once completed, the measured activity is corrected by each tube's calibration factor.

6. All readings should fall within the range of  $\pm 10\%$  of the average activity value.

**EVALUATION**

The measured source readings are compared with previous results.

**ACTION LIMITS AND  
REMEDICATION**

The percent deviation of the measured activity to the previous results must be within  $\pm 10\%$ . If the deviation is greater than  $\pm 10\%$ , mathematically corrected dosage reading can be applied, or the unit can be serviced.

#### 4. Dose Calibrator Accuracy

<b>PURPOSE</b>	To verify proper performance and accurate reading of the dose calibrator
<b>FREQUENCY</b>	Testing is to be performed at installation, annually, and after major repair.
<b>REQUIRED EQUIPMENT</b>	One or more NIST traceable, long-lived standard such as Cs-137, Co-57, Ba-133, or Na-22 to be used as the test source.
<b>TEST PROCEDURE</b>	<ol style="list-style-type: none"><li>1. Perform a "Test" measurement of the battery voltage (if applicable)</li><li>2. Perform a zero adjustment (if applicable)</li><li>3. Perform a background check/correction</li><li>4. Place the test source into the chamber of the dose calibrator and select the proper radionuclide on the dose calibrator</li><li>5. Measure the source and record the reading</li><li>6. If additional test sources are available, steps 2 and 3 should be repeated for each source</li></ol>
<b>EVALUATION</b>	The actual activity in the test source(s) must be calculated by correcting for decay of the source(s). The measured source reading is then compared with the decay-corrected actual reading.
<b>ACTION LIMITS AND REMEDIATION</b>	The percent deviation of the measured activity from the decay-corrected activity must be within $\pm 10\%$ . If the deviation is greater than $\pm 10\%$ , the instrument should be taken out of use and the unit must be serviced. A lower threshold such as $\pm 5\%$ could be used for monitoring performance for potential need for servicing or replacement.



## C. Uptake Probes and Well Counters

Uptake probes are non-imaging measurement systems used in the NM facility for measuring thyroid uptake/function. Well counters are typically used for high sensitivity counting of radioactive specimens such as radioactive blood, urine samples, or survey wipes to assess contamination. Uptake probes and well counters have very similar QC procedures.

### 1. Uptake Probe & Well Counter High Voltage Adjustment/ Energy Calibration (Auto Calibration)

<b>DESCRIPTION</b>	It performs an adjustment of the PMT high voltage so that the energy pulse height is accurately centered to the corresponding voltage. This corrects the system's performance against any high voltage changes or other drifts in electronic components. Typically, a 0.5- to 10- $\mu$ Ci (0.0185- to 0.37-MBq) Cs-137 source is used for this test; most Biodex systems use a 10- $\mu$ Ci (0.37-MBq) button source, whereas most Capintec systems use a 0.5- $\mu$ Ci (0.0185-MBq) Cs-137 rod source. This test also checks the quality of the energy spectrum's photopeak for Cs-137 and ensures that the shape and width of the peak are of good quality, thus translating to an acceptable energy resolution at FWHM.
<b>FREQUENCY</b>	Daily before the first procedure.  Annually, verified or performed by QMP.
<b>TEST PROCEDURE</b>	Ensure there is low background radiation in the area before proceeding.  After the system has been turned on for at least 1 hour so that the NaI(Tl) crystal and PMT are sufficiently warmed-up, the Cs-137 source is positioned appropriately centered in the FOV of the detector. For this and all other tests of the uptake probe, consistent placement of the QC source with respect to the detector is critical. Depending on the system, source positioning can vary; for example, Biodex systems place the button source at a distance from the detector whereas Capintec systems place the rod source on the detector itself. The system's software will perform automatic gain adjustments so that the Cs-137 photopeak is centered at 662 keV. The percent energy resolution at FWHM for Cs-137 is also calculated and should generally be less than 10%.
<b>EVALUATION</b>	This is a PASS/FAIL test as determined by the system. If the system fails to place the Cs-137 photopeak of 662 keV to within an acceptable range of positive/negative channels in the MCA (multichannel analyzer), it will generate an error message. Similarly, if the percent energy resolution at FWHM is higher than the acceptable limit, the system will fail. As detectors age, the percent energy resolution might slightly increase over time, whereas a rapid increase might indicate a problem with the

detector assembly. If the test failed, it should be repeated by ensuring there is low background, the source is appropriately positioned, and the system has been turned on long enough for the electronics to stabilize.

#### **ACTION LIMITS AND REMEDIATION**

If the test fails repeatedly, even after rebooting and restarting, the problem should be reported to service engineering for appropriate evaluation and possible repair as needed.

**2. Uptake Probe & Well Counter Constancy**

<b>DESCRIPTION</b>	This test compares the Cs-137 source activity entered at setup and decay corrected for time, with the activity measured by the probe. The counts measured in the Constancy test are converted to activity using efficiency values obtained at efficiency calibration.
<b>FREQUENCY</b>	Daily before the first procedure.  Annually, verified or performed by QMP.
<b>TEST PROCEDURE</b>	Ensure there is low background radiation in the area before proceeding.  After the system has been turned on for at least 1 hour so that the NaI(Tl) crystal and PMT are sufficiently warmed-up, the Cs-137 source is positioned appropriately centered in the FOV of the detector. Depending on the system, the source positioning can vary with Biodex systems placing the button source at a distance from the detector, whereas the Capintec systems place the rod source on the detector itself. The system collects counts from the Cs-137 over sufficient preset time and then calculates the percent Constancy deviation between the calculated and measured activity.
<b>EVALUATION</b>	This is a PASS/FAIL test as determined by the system if the Constancy deviation is outside the range of $\pm 10\%$ . If the test fails, the autocalibration or high voltage adjustment test should be performed and the test should be repeated. The measured efficiency of the system for Cs-137 might also need to be verified.
<b>ACTION LIMITS, REMEDIATION</b>	If the test fails repeatedly with deviation greater than 10%, even after rebooting and restarting, the problem should be reported to service engineering for appropriate evaluation and possible repair as needed.

#### 3. Uptake Probe & Well Counter Chi-Square Test

**DESCRIPTION** This test performs a series of measurements and checks if their random variation is statistically consistent with a Poisson distribution. This test checks the overall counting performance of the system.

**FREQUENCY** This test should be performed each time the system is turned off and on. It should also be performed at a minimum on a quarterly basis and verified or performed by the QMP annually.

**TEST PROCEDURE** Ensure there is low background radiation in the area before proceeding.

The Cs-137 test source should be appropriately positioned centered in the FOV of the detector. The system's software performs a series of repeated measurements, for example, 10 repetitions for 60 seconds each, and then calculates the statistical value of chi-square. The result is compared with the acceptable limits for the chi-square statistic (eg, for 10 measurements, this would be from 4.17 to 14.68 at the 90% CI).

**EVALUATION** Because of the statistical nature of this test, the results are expected to vary while they should remain within the acceptable tolerance window. This is a PASS/FAIL test as determined by the set tolerance of the system. If the test fails repeatedly, the autocalibration or high voltage adjustment test should be repeated.

**ACTION LIMITS, REMEDIATION** If the test fails repeatedly, even after rebooting the system, the problem should be reported to service engineering for appropriate evaluation and possible repair as needed.

#### 4. Uptake Probe & Well Counter Minimum Detectable Activity

##### DESCRIPTION

This test calculates the minimum detectable activity (MDA), which is the smallest activity that can be detected for a specific radionuclide or energy range. The test is performed without any radioactive sources or background that could affect the measurement in the selected ROI energy range. A primary applicability of the MDA test is for wipe counting in the well counter.

##### FREQUENCY

This test should be performed according to manufacturer and/or QMP recommendations. Typically, following high-voltage changes as a result of moving the instrument to a new location or changes in the background from radiation sources.

##### TEST PROCEDURE

The MDA test procedure provided by the device manufacturer should be followed. Typically, it should be ensured that there are no sources of background radiation that could influence the counting measurement. No source should be placed in the FOV of the detector. The system measures the counts for a preset time for the selected radionuclide's energy range. The system then calculates the MDA in disintegrations per minute (dpm) or  $\mu\text{Ci}$  (kBq).

##### EVALUATION

The obtained MDA should be within expected limits for the specific radioisotope. If the result exceeds acceptable limits, it should be repeated after ensuring the background is clear of any radiation sources that could affect the counting. If the MDA test fails again, autocalibration or high voltage adjustment should be considered, and test should be repeated.

##### ACTION LIMITS AND REMEDIATION

If the test fails repeatedly, even after rebooting the system, the problem should be reported to service engineering for appropriate evaluation and possible repair as needed.



Figure 4-14. Quality control configurations for two different types of commercial uptake probes.

## Resources

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