AAPM REPORT NO. 74

QUALITY CONTROL IN DIAGNOSTIC RADIOLOGY

Report of Task Group #12
Diagnostic X-ray Imaging Committee

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July 2002

Published for the
American Association of Physicists in Medicine
by Medical Physics Publishing

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Medical Physics Publishing
4513 Vernon Blvd.
Madison, WI 53705-4964
Telephone: 1-800-442-5778 or
608-262-4021
Fax: 608-265-2121
Email: mpp@medicalphysics.org
Web site: www.medicalphysics.org

International Standard Book Number: 1-888340-33-9
International Standard Serial Number: 0271-7344

Published by Medical Physics Publishing
4513 Vernon Blvd., Madison, WI 53705-4964

Printed in the United States of America

This report is dedicated to the memory of

Raymond P. Rossi

Mentor, Colleague, Friend

The task group also wishes to honor

Hy Glasser

A leader in the field of QC instrumentation development and marketing

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INTRODUCTION

In 1977, the American Association of Physicists in Medicine (AAPM) published a quality assurance protocol aimed at providing guidance to a radiologic technologist involved in the implementation of a quality assurance (QA) program in diagnostic radiology. Since the time of that writing, diagnostic radiology has undergone fundamental changes that have directly influenced the requirements of such a program. Equipment has become more complex with the maturation of digital radiography and fluoroscopy. We have witnessed the proliferation of mid-frequency generators from primarily portable operations to standard radiographic-fluoroscopic systems and to cardiac imaging and digital subtraction angiography. Our ability to test radiographic systems without invasive measurement has developed along with the computer industry, making possible the capture of test data directly into a database running on a laptop computer.

In 1994, the AAPM published a task group report on the Role of the Clinical Medical Physicist in Diagnostic Radiology.[1] That document includes this statement:

> *A primary responsibility of the medical physicist in an imaging program is the development and supervision of a quantitative quality assurance program.*

The responsibility for establishment of a quality control (QC) program has clearly moved out of the domain of the radiologic technologist and into that of the diagnostic medical physicist. The diagnostic medical physicist must be knowledgeable in current equipment designs, intended use, and the appropriateness of the various test instruments that may be used in performance evaluation. The diagnostic medical physicist acts as a local expert on Joint Commission on Accreditation of Healthcare Organizations (JCAHO), state, and federal requirements concerning quality control, equipment performance, and radiation safety. As such, the medical physicist needs to be able to provide a well designed QC program that addresses the needs of the clinic by assuring consistent optimal image quality, a safe work environment, and compliance with the various regulatory agencies, all at a reasonable cost to the institution.

The intent is for this report to be used by the consulting or resident diagnostic medical physicist. As such, it will not provide instructions for how to perform individual tests. Reference will be made, however, to where the reader may find such information and which resources the authors have found to be most helpful. We shall restrict our recommendations to the identification of which parameters are essential for a given type of x-ray imaging equipment and what minimum performance criteria should be met in order to achieve acceptable image quality. The report will outline the essential components of a QC program in diagnostic radiology that can be used by the diagnostic medical physicist as a guide when designing such a program for a given clinical operation. Specific tests will be recommended for most of the common radiological imaging equipment found in a typical, large radiology department. A rationale for determining efficient testing frequencies

based on criticality and track record of the equipment is also included. Programs may be tailored to meet the needs of any individual clinic by including only the tests that are appropriate for the equipment at that clinic. It is the responsibility of the reader to be familiar with state and local regulations, which may contradict these recommendations. Also, federal regulations cited as references in this work are subject to change.

The task group recognizes that the availability of a standard set of forms for data collection is of significant interest to the audience of this report. Several such comprehensive forms are under development at the time of this writing. However, in the interest of brevity, they were not included in this report.

1 THE QUALITY CONTROL PROCESS

1.1 Equipment Selection

Quality begins with proper equipment selection.[2] The diagnostic medical physicist, having been educated in the administrative, technical, and clinical aspects of equipment performance, possesses a unique vantage point from which to assess appropriateness of imaging equipment. Equipment must be appropriate in terms of its ability to deliver the quality necessary for a particular imaging task at a cost to both patient and hospital (or clinic) that is reasonable in terms of dose, dollars, and downtime. The medical physicist must be an integral component of the equipment selection process.

Prior to the request for a quotation on any imaging device, the medical physicist should compile a set of performance specifications upon which such a quote should be based. These bid specifications will form the basis for acceptance tests to be performed upon installation. As such, they will necessarily be detailed and should be as specific as possible in terms of the tests to be performed and the results expected. The performance levels stated in these specifications should reflect the anticipated needs for successful utilization of the procedure room as envisioned by the radiologists and technologists. Specifications should include requirements for:

- Generators [maximum voltage, current, Automatic Exposure Control/Automatic Brightness Control (AEC/ABC), rated power, waveforms, input requirements, etc.]
- X-ray tube assemblies (focal spot sizes, anode and housing capacity and cooling rate, target angle(s), collimation, etc.)
- Patient support assemblies (dimensions, weight, capacity, motions, etc.)
- Buckys and grids
- Image receptors or video chains (resolution, contrast detectability, field of view, bit depth, dynamic range, functional capabilities, etc.)
- Display systems

- Archival systems
- Gantry configuration [source-to-image-receptor-distance (SID), motions, positioning, etc.]
- Peripheral devices (film changers, injectors, film processors, hard-copy devices, etc.)

This information may then be used to assist in evaluation of equipment during the selection process.

1.2 Acceptance Testing

Once an appropriate system has been selected and installed, it is the diagnostic medical physicist's responsibility to assure that the equipment functions safely, according to all published claims made by the vendor, and as agreed to in any contract-related documents created during the selection process (including the bid specifications). Documentation of the system performance during the warranty period may become a critical issue and hence must be carefully maintained.[3]

1.3 Quality Control

Following successful installation and acceptance, equipment must be monitored on an ongoing basis to ensure continued, reliable performance. This ongoing, periodic evaluation procedure is quality control (QC). The purpose of QC testing is to detect changes that may result in a clinically significant degradation in image quality or a significant increase in radiation exposure. For example, suppose one decides to maintain the image intensifier input exposure rate (IIIER) of a fluoroscopic imaging system at 100 ± 30 μR/sec based upon a proven history of acceptable performance. We know from experience that if the exposure rate drops below the minimum level, the radiologist will notice that the images have become excessively noisy and our radiology staff will complain. At the other extreme (the upper limit), we wish to maintain the exposure to our patients at a level such that a further increase in dose yields little improvement in image quality. We want to test the unit frequently enough to determine whether a change in the IIIER has occurred before the radiologist indicates that the images are too noisy. How frequently must we carry out the test to have reasonable confidence that the unit is functioning properly between tests?

The frequency of any QC test depends on many variables including:

- The inherent variability of the process or equipment
- The age, reliability, and frequency of use of the equipment
- The criticality of the element in the imaging chain

If a process is quite variable, then it must be monitored more frequently than one that is inherently stable. Often, older equipment is less reliable and less stable.

This equipment will have to be monitored more frequently than newer, more stable equipment. Finally, a critical element is one that can significantly affect image quality or patient dose. For example, the entire imaging chain may depend on the photographic processor to produce the final product, a radiographic image. This along with the fact that the photographic process has the potential to vary significantly indicates that the processor must be monitored more frequently than any other element in the imaging chain.

In a new QC program, or with new equipment, data should be acquired more frequently in order to obtain a greater amount of baseline data rapidly. This also provides valuable experience to those carrying out the QC program over a short period of time. This larger amount of data allows determination of the variability in the processes, and hence, the testing frequencies required to provide appropriate monitoring.

Let's consider the measurement of kilovoltage (kV), using a non-invasive kV meter, as an example. For most radiographic equipment this test is typically carried out annually. At the start of the QC program it would be worthwhile to perform this test monthly for 4 to 6 months and then quarterly for the next 6 to 12 months. This gives the QC technologist experience in making this measurement and provides an indication of variability of the data produced from specific generators. After 6 to 12 months the medical physicist can determine the stability of the generator performance by careful evaluation of the data and arrive at an appropriate test frequency. If it is stable, then annual monitoring is probably adequate. However, if there is a significant amount of variability, then more frequent monitoring, e.g., quarterly or semiannually, may be indicated.

The more completely your institution can control the system being monitored, the lower the testing frequency required. For example, if photographic chemicals are mixed from bulk concentrates at your institution, each batch of chemicals is sensitometrically tested prior to putting them in the replenishment system, and the volume of films processed daily is high in each processor and is consistent (200 35×43-cm films or equivalent every day), it may be justified to reduce the frequency of photographic processor QC to twice weekly or even weekly. However, anytime one processor appears to be less consistent, it is essential to increase the monitoring frequency. Again, because of the likelihood for component failure and the variability of maintenance quality, biweekly processor QC testing should be considered the minimum frequency even under ideal conditions due to its potential, inherent variability.

In summary, several actions should be considered when establishing QC test frequencies, including:

- Determine the testing frequencies recommended in the literature[4]
- Carry out the tests at a frequency greater than recommended when starting your QC program to provide experience for the QC technologist and to obtain a larger base of data more rapidly

- Drop back to the testing frequencies recommended in the literature after 6 months to 1 year if the data support this change
- Consider reducing test frequencies after the QC program has been operating for a considerable period of time
- Constantly monitor QC results and reevaluation of test frequency. This should be performed by a diagnostic medical physicist and is essential

Test frequencies should also be temporarily increased after any component failure to validate the effectiveness of remedial actions taken. Test frequency may have to be increased as equipment ages and reliability degrades.

1.4 Documentation

Test results should be recorded in a database for analysis.[2] Performance comparisons should be made routinely to assure constancy in the performance of each device as well as consistency between devices. For instance, in a department with four chest Bucky devices, it is essential that the generator, phototimer, and processor system in all the rooms produce the same radiographic density and contrast for a given phantom. Routine comparisons of results between rooms and processors will assure consistency.

1.5 Staffing Considerations

Routine (daily, weekly, and monthly) QC testing should be performed by a technologist and reviewed periodically by a diagnostic medical physicist. This testing is normally performed with simple QC instruments and phantoms. Tests with quarterly to annual frequencies may be performed either by a diagnostic medical physicist or a well-trained QC technologist working under the supervision of a medical physicist, depending upon the complexity of the test and the competency of the technologist. Responsibility for training of all personnel utilized for quality control and analysis of all results is the responsibility of the diagnostic medical physicist. Recommendations for physics staffing are given in the AAPM Report No. 33.[5]

2 QC INSTRUMENTATION

The choice of instrumentation for performance of QC and acceptance testing depends upon the type of radiological equipment to be evaluated and the intended user. Instrumentation needs should be determined on a case-by-case basis.

To assist in the selection of appropriate instrumentation, refer to AAPM Report No. 60.[6] The report contains a compilation of instrumentation requirements for use in evaluation of radiographic and fluoroscopic equipment along with recommended

performance capabilities that can be used for specifications prior to purchase. The instrumentation is intended for use by or under the direction of qualified diagnostic medical physicists. There are specific recommendations on routine QC instruments as well as more sophisticated instrumentation useful for higher level testing such as may be necessary for acceptance tests. Specific recommendations on the minimum instrumentation needed to perform QC testing is given in Section A of the report.

3 THE PHYSICS REPORT

When the primary role of the diagnostic medical physicist was to determine if equipment met safety standards, communicating the results of the survey consisted of little more than describing the problem and asking service engineers to correct the problem. However, the role of the medical physicist has expanded and the communication of the results of medical physics surveys has become a much more important part of medical physics practice. The ability of the medical physicist to properly communicate the results of his/her work is an important part of the professional practice of medical physics.

The proper communication of the results of a medical physics survey may be considered analogous to the communication of the results of a radiology procedure. Medical physicists can learn the basics of the process from our radiologist colleagues. Proper communication of the results of radiology procedures, both orally and in writing, constitute an important part of a radiologist's activities. Accuracy, clarity, and simplicity are appreciated by those who receive the reports. Clear and decisive communication is imperative.

Medical physicists should march under the same flag as the radiologists. As medical physicists, we should strive to produce reports that provide clear information in format that is easy to use. Verbal communication is an important part of medical physics work. Information that is critical cannot wait for a written report to be developed. It is also vital for the medical physicist to maintain good relations with radiologists, technologists, and administrators so they feel free to contact the medical physicist with their questions. Meetings with these key individuals as part of a medical physics survey are helpful. The vampire-physicist who only appears at night and only leaves reports is not providing appropriate service to the client. Even though the importance of good relations between medical physicists and their clients cannot be emphasized too strongly, the rest of this brief chapter will concentrate on the written report.

3.1 The Environment of the Report

The medical physicist's report is inserted into a complex imaging environment. The report may be reviewed by individuals with a range of backgrounds, from physicians to service engineers. See Table 1.

Table 1. Persons Who may Read a Medical Physics Report

Physicians
Administrators
Technologists
State Regulators
Federal Regulators
Accreditation Bodies
Service Engineers

The people who review the report may have widely divergent interests, knowledge of equipment function, and command of written English. In extreme circumstances, the medical physicist's report may become part of a legal proceeding. In the consulting environment the medical physicist may not be available, except by phone, to help interpret the written document. The multiplicity of uses of the medical physicist's report suggests that the medical physicist should adopt a strategy for dealing with this complex environment.

3.2 Report Structure

While reports may be formatted in many ways, a reasonable strategy is to have several "layers" to the report. A possible format is a brief introduction that summarizes the whole environment, followed by detailed recommendations, expanded text material, and then detailed data. In some cases, such as mammography, special forms must be filled out and other supporting material such as continuing education credits, certifications, and licenses must be included.

The initial section should briefly explain what equipment or program the medical physicist was reviewing and summarize the medical physicist's overall judgment about the situation.

3.2.1 Recommendations

The results of a medical physicist's survey should be presented in the form of a series of recommendations. These recommendations are the summary of our advice for improving the overall imaging environment. Unfortunately, in some cases, the recommendations may be the only part of the report that is actually read. Many medical physicists find it helpful to divide recommendations into two groups. The first group includes recommendations that must be acted upon because of regulations. The second group includes those recommendations that the medical physicist believes are useful but are not mandated by regulations.

The recommendation should contain a series of elements to clarify to the customer what course of action to follow. A statement of the problem, reference to existing standards, a description of the perceived cause of the problems, a suggested course

Table 2. A Sample Recommendation

Statement of Problem	The artifact films for the mammographic unit show significant artifacts that should be corrected. These artifacts are causing image quality problems with the ACR phantom and can be seen on the clinical images.
Reference to Standards	These artifacts are severe enough to cause the unit to fail the ACR artifact test described on page 173 of the ACR Mammography Quality Control Manual.
Cause of the Problem	These artifacts appear to be due to a problem with the molybdenum filter.
Recommended Course of Action	Please have the service engineer check the filter for corrosion or damage and correct the problem. I left a copy of the artifact film with Ms. N. Jones, the QC technologist.
Recommended Follow-up	After the problem has been corrected, please send me a film of the ACR phantom and an artifact film. I will review the films and send you a final report.

of action, and recommendations for follow-up are a reasonable set of elements that should be included in the recommendations (see Table 2).

Statement of problem. The first element of recommendation is a clear statement of the problem. When the problem is regulatory in nature, this can be simple; but for issues of image quality, it is sometimes difficult to clearly state what the problem is. The more the medical physicist knows about the particular imaging modality, the more likely the medical physicist will be able to make an intelligible statement of the problem. Knowledge includes the physics underpinning of the modality, the technical aspects of the imaging device, the technical aspects of ancillary equipment (film processors, computer work stations), and the clinical environment in which it is used. The medical physicist should also be familiar with common problems that occur and how they are corrected. The problem should be stated so that the reader can determine the effect of the problem on clinical practice.

Reference to standards. If the problem is related to a published standard or regulation, this should be referenced. Standards referenced can include state or federal regulations, standards from professional societies [AAPM, American College of Medical Physics (ACMP), American College of Radiology (ACR)], or recommendations from the literature. If the standard is not likely to be available to the site, it is helpful to include a copy in the report. Budgetary restrictions sometimes make it difficult for departments to correct problems. If a published standard exists, then it may be easier to justify making the correction.

Cause of the problem. The cause of the problem may or may not be known to the medical physicist. If the medical physicist knows the cause of the problem, the

recommendation should briefly explain it. When the cause of the problem cannot be determined, the medical physicist should give the site guidance on what steps should be taken to determine the cause of the problem and how to correct it. When the medical physicist is available at the site, the medical physicist should participate as much as possible in determining the cause of the problem. This helps to ensure that the cause is properly determined and may even be an educational experience. When the medical physicist is serving in a consultant's role, the medical physicist should provide written guidance to the site on how to proceed to determine the cause of the problem.

Recommended course of action. The recommendation should include a suggested course of action. This can be as simple as recommending that service engineers be contacted to correct the problem or a recommended change of practice to improve image quality. Examples would be changing a screen film combination or changing the technique used for a computed tomography (CT) examination. Recommendations of this type may require that the medical physicist get a consensus from other parties such as the radiologist, the technologist, and the administrator. If at all possible, the medical physicist should speak with these people directly; but if that is not possible, the recommendation should be worded in such a way that it will encourage consideration and acceptance by all parties.

Recommended follow-up. The recommendation should include a recommended course of follow-up so the medical physicist can be comfortable that the problem is corrected. If it is within the medical physicist's own institution, follow-up should be straightforward so that the medical physicist can directly supervise the process and make the necessary measurements after the work has been completed. When the medical physicist is working in the role of a consultant, follow-up is more difficult because the site may be some distance away and may be concerned about paying for additional follow-up visits. The medical physicist can request copies of service records, quality control records, or phantom films to reduce the need of on-site follow-up. Nevertheless, on-site follow-up is sometimes necessary to ensure the recommendations have been acted upon.

Medical physicist follow-up. When the medical physicist is satisfied that the recommendations have been acted upon it is appropriate to provide a final brief report to indicate that all the recommendations have been acted upon.

3.3 Description of Tests and Data

Descriptions of the tests that were done and the data collected can be useful for service engineers and other medical physicists. Include a section in the report that describes the nature of each test and the results. This information is somewhat like the materials and methods section in a scientific paper and allows the reader to determine what was measured, how it was measured, how the data was interpreted, and what standards were used. Finally, attach all the data collected. This may be

in the form of a spreadsheet. The data are useful to service engineers who have to take corrective action. It is also of interest to anyone who wants a detailed knowledge of the performance of the equipment, and for the next medical physicist who surveys the equipment.

3.4 Special Cases

Sometimes the medical physicist may have advice to the site that is not an appropriate part of a report that may be read by service engineers and regulators. An example might be the recommendation to consider replacing a technologically obsolete unit. Such a recommendation might give a service engineer information that could be used to a site's disadvantage in the purchase environment. It might also influence a regulator's perception of a device that may meet all existing regulations. Recommendations that have a restricted audience should be included in a separate document provided to appropriate individuals. In any case, the medical physicist should always consider that written reports may be become public either accidentally or as part of a legal process. Unprofessional remarks about equipment, companies or individuals are never appropriate. Sometimes the medical physicist becomes involved in conflicts between a site and a regulatory agency. In this case, the medical physicist should serve primarily as an agent for the medical physicist's client but should not participate in an attempt to deceive a regulatory agency by obscuring or falsifying facts.

3.5 Notes on Medical Physics Communication in the Academic Environment

The academic environment that has subspecialty radiologists, specialized medical physicists, physics students, physics residents, radiology residents, and separate radiology divisions poses special challenges and opportunities for the communication of the results of medical physics activities. In this environment, where one would expect the highest quality medical physicist work, the results are often not properly transmitted to all involved individuals.

It is important to train radiology residents in reading medical physics reports, analyzing the contents of medical physics reports and selecting a medical physicist. Radiology residents have exposure to a medical physicist in the classroom; but if the residents do not have the experience of dealing with medical physics reports, they will not be equipped to work with medical physicists when they go into community hospitals. The academic medical physicist must involve radiology residents in the clinical practice of medical physics as part of their training.

The same situation exists for radiologic technologists. As part of their training, technologists should be prepared to interpret medical physics reports and to work with medical physicists in solving problems. In the past, most radiology administrators

were radiologic technologists. This situation is rapidly changing. In academic institutions with training programs for administrators, medical physics participation in the training of administrators would be useful.

In an academic practice the medical physicist may directly supervise the service engineers so that technologists and physicians do not fully participate in the medical physicist surveys. Thus, it becomes imperative for the medical physicist to communicate the results of these surveys to physicians, administrators, and technologists in the various subspecialty sections. There are many ways that the medical physicist can ensure that the physics work is integrated into the department. These include meetings with departmental sections, section heads, lead technologists, and administrators; participation in technologist and physician quality assurance conferences; and wide dissemination of the written reports. Follow-up with physicians and technologists when courses of action in recommendations are acted upon is also important.

3.6 Conclusions

The medical physics report is the primary method to transmit the results of medical physics surveys. Thus the report must be clear, accurate, and to the point. Since many individuals read the report, the report must be structured to meet all their needs. Recommendations should clearly state the problem, provide guidance on how to proceed, and provide a mechanism for follow-up. Medical physicists in academic environments have a special obligation to train radiologists, technologists, and administrators so that they understand the nature of medical physics, can select an appropriate medical physicist, and can interpret a medical physicist's report.

4 REPEAT RATE ANALYSIS

One of the main goals of any radiology facility should be to minimize patient exposure. One way of accomplishing this goal is through minimizing the number of repeat exposures performed. By definition, repeat films are those patient radiographs that are not diagnostically acceptable and require an additional exposure of the patient for the same view. Evaluation of repeat rates for a facility can serve as a means of improving patient care, decreasing exposure, and reducing film costs.

Repeat rate analysis should be performed on a regular basis. To assure meaningful results, recommended frequency for performance is quarterly with a minimum volume of 250 patients. It is recommended that the same individual be responsible for performing the analysis, as film viewer differences can affect the outcome of the study. Other factors that can affect the facility repeat rate and should be considered are:

- Data collection method
- Facility staff makeup and experience
- Staff awareness of repeat rate being performed
- Weekend, evening, or day shift
- Facility standards

In addition to the total number of films, the causes of the repeats should be evaluated. The repeat films should be separated into categories and repeat rates calculated for each category. The following are some suggested categories for evaluating repeat films:

- Patient positioning
- Patient motion
- Artifacts
- Film fog
- Equipment malfunctions
- Over- or underexposed films
- Examination room
- Technologist
- Anatomical view

It may be necessary to further evaluate the selected categories (i.e., over- or underexposed films) and the underlying cause (i.e., radiographic equipment, processing, technique charts). If repeats appear to be related to an individual radiographer, care should be taken to address the problem in an educational manner. Particular care should be taken to make repeat rate analysis a learning experience, not a disciplinary one. Any area showing significant repeat rates is an indication of the need for continuing education or review by the facility staff. When performing repeat rate analysis, the number of unnecessary repeats also needs to be addressed.

As a further evaluation facility repeat rates can be compared to national repeat rates. When doing these comparisons it is important to remember that rates may vary from the national rates due to the structure of the facility's film analysis. For mammography, the ACR recommends that the repeat rate be less than 5%.[7] This is consistent with the overall national repeat rate for radiographic films, including mammography.[8,9,10,11] Repeat rate should not be construed as a measure of overall institutional quality. Facilities where radiologists are lax in demanding high quality images can have very low repeat rates.

Although not considered repeat films, a facility may want to evaluate extra films requested by the referring physician and the reason for those films. Evaluation of extra films may indicate a need to re-evaluate a facility's standard procedure protocols. In addition, evaluation of the amount of green or clear film may help in an overall film cost reduction for the facility.

5 QUALITY CONTROL OF RADIOGRAPHIC UNITS

Radiographic units exist in a wide variety of configurations. There are many references in the literature that contain appropriate methodology for equipment evaluation (see **References** and **Suggested Reading** at the end of this report).

5.1 Daily Visual Checks

Prior to first-patient use, and on a daily basis thereafter, the system should be evaluated by the technologist for functionality of all components and accessories. Attention should be paid to items that may pose a hazard to operators or patients such as frayed cables, exposed sharp edges, nonfunctioning interlocks, etc. This should be included as part of a morning warm-up routine. This routine also provides an opportunity to verify adequacy of supplies and availability of accessories.

5.2 X-ray Tubes and Collimators

Test all parameters at least annually.

5.2.1 Beam Quality

The beam quality has a major impact on patient dose and a somewhat smaller impact on the quality of the final image. Beam quality will change as the x-ray tube ages due to deposition of target material on the inside of the tube window and to roughening of the target track. This measurement should be made at least annually and whenever the x-ray tube or collimator is replaced or serviced. Consult 21 CFR[11] or state regulations for minimum half-value layer (HVL) requirements on your system.

5.2.2 Light Field/X-ray Field Alignment (Congruence)

The alignment between the light field and the radiation field permits the technologist to position the field to expose only the anatomy of interest. Misalignment may result in unnecessary or repeat exposure. Testing should be performed at least annually on new equipment. Test frequency may need to be increased as the system ages (see section 1, **The Quality Control Process**). The functionality of the field light should be confirmed as well as the adequacy of the field illumination. The Code of Federal Regulations (21 CFR) currently requires that the individual x-ray field and light field borders agree to within ±2% of the SID.

5.2.3 X–Y Scale (Field Size Indicator) Accuracy

The accuracy of the collimator X–Y indicators permits proper sizing of the x-ray field when the collimator light is nonfunctional or poorly visualized due to patient positioning or anatomy. Accuracy should be evaluated annually or as often as

necessary to maintain correct operation (see section 1). 21 CFR[11] currently requires that the x-ray field size and field size indicators agree to within ±2% of the SID.

5.2.4 Positive Beam Limitation System (PBL)

PBL (or automatic collimation) prevents the collimated x-ray field from exceeding the size of the image receptor in use when the system is operated in a standard, calibrated geometry. The edges of the x-ray fields and corresponding image receptors should agree to within ±2% of the SID, the system should appropriately indicate when PBL is and is not activated, and the system should also allow for manual override (or "coning down") to field sizes smaller than the receptor dimensions.

There are several variations of the automatic collimator. All PBL systems must sense the size of the image receptor and allow adjustments to be made to the field size such that it does not exceed the size of the image receptor at the calibrated SID. Some systems sense the SID as well, allowing automatic adjustment at either a variety of standard SIDs (typically 40, 48, and 72 inches) or over a range of SIDs that includes some standard distance (typically 40 in.). When the system is not in a calibrated position, either an exposure prevention (or "Hold") circuit should be energized (and indicated) or a ("Manual") mode should be clearly indicated. A manual override that allows adjustment to field sizes smaller than the image receptor (cassette) must be present and functional as well. The particular type of PBL system in use will need to be determined and tested accordingly.[13] Proper operation should be confirmed, and correct sizing verified either with a properly aligned light field or with accurate field size indicators. Proper operation should be confirmed with at least two different image receptor sizes, one no larger than 8×10 in. and one no smaller than 14×17 in. Tests should be performed annually or as often as necessary to maintain correct operation and alignment (see section 1).

5.2.5 X-ray Beam–Bucky Alignment

The central ray of the x-ray beam should be aligned with the center of the image receptor, when placed in the Bucky, to prevent image cut-off. Most systems utilize a combination of both electromechanical détentes and alignment lights to indicate when the system is correctly aligned. Federal regulations[11] currently require that the edges of the x-ray fields and corresponding image receptor edges agree to within ±2% of the SID. Tests should be performed at least annually or as often as necessary to maintain correct alignment. Older systems may require more frequent evaluation (see section 1).

5.2.6 Focal Spot Size

The size of the radiation source has considerable impact upon the resolution in the image. Focal spot sizes should be measured according to National Electrical Manufacturers Association (NEMA)[14] guidelines (slit camera) at acceptance or

replacement to ensure proper performance.[15,16,17] For general purpose imaging [head & neck, abdominal, spine, long bone, genitourinary (GU), etc.], a good rule of thumb suggests a nominal focal spot dimension of approximately 0.1% of the SID. For detail imaging (pediatric, extremities, long bones, etc.), the measured focal spot dimensions should be less than 0.05% of the SID. These suggested specifications result in a 2.0, 1.2, and 0.6 mm nominal focal spot sizes for chest, general purpose, and detail radiography respectively. Blooming characteristics and resolving capability should be evaluated at acceptance using a star pattern.[15,16,17]

5.3 X-ray Generators

The accuracy of the technique indicators is crucial to the consistent production of high-quality radiographs from room to room and from patient to patient. Depending on intended use, the range of techniques to be measured may vary. For example, a generator placed in a room intended for dedicated chest radiography need only function with high accuracy between 100 and 140 kVp, and at tube currents necessary to give proper film density in 5 to 30 msec. The same generator used in a general radiography room must maintain its accuracy over a much wider range (e.g., 50 to 120 kVp, and at 20% to 100% rated power). Performance should be spot-checked across the entire selectable range with particular attention paid to the most commonly used techniques. The reader is referred to AAPM Report No. 14[18] for a thorough explanation of generator performance concepts. All generator parameters should be evaluated at acceptance and at least annually thereafter (see section 1).

5.3.1 Kilovoltage Calibration

Accuracy of the kilovoltage indicator is most easily evaluated by use of a noninvasive kVp meter. Caution must be exercised in orienting the device in the beam to avoid systematic errors. One must avoid errors due to kV meter frequency response when evaluating medium-frequency generators.

Noninvasive kVp meters do not directly measure kVp, but rather measure the beam hardness and relate it to actual kilovoltage used under the calibration conditions in the laboratory. Other variables such as anode angle, degree of anode pitting, and added and inherent filtration can influence the noninvasive kV measurement. Particular attention should be paid to some angio and cardiac units that are designed with very heavy added filtration. Some of these units employ copper filtration to match the energy spectrum to the k-edge of contrast media. This type of filtration can have a considerable effect on the noninvasive kV measurement. Noninvasive kV device results may require the manual application of HVL-dependent correction factors to achieve published accuracy.

Invasive test devices (high voltage dividers) may also be used.[18,19,20] These devices require a more thorough understanding of both the generator design and divider operation. Installation of such a device carries a risk of exposure to high voltage, which

may be lethal to operators and damaging to equipment if improperly connected. For these reasons, invasive test devices are not recommended for routine QC. Whatever device is used, the medical physicist must understand the limitations and inherent inaccuracies of the test instrument. Technologist assistants should be carefully instructed in proper test procedures to avoid misleading test results.

kV waveforms in the useful range should be obtained, evaluated, and documented during acceptance testing for future reference. In general, waveforms should be stable to within ±5% from initiation to at least 100 msec (longer stability performance may be necessary for some clinical applications). There should be no spikes or drop-outs during any exposure. Rise and fall times should represent less than 1% and 10%, respectively, of the total exposure time for the shortest clinical exposure times anticipated.

For single- and three-phase generators used in general purpose radiography, kV indicators should represent the average of the peaks in the voltage waveform to within ±5%. Older generators may not be capable of meeting this specification, in which case an absolute maximum tolerance of ±4 kVp should be used. For capacitive discharge generators, the indicator should show the maximum, or starting, potential of the kV pulse. Mid-frequency generators present a special problem in defining tube potential. For heavily filtered kV pulses, the waveform may be interpreted as direct current (DC). The average DC value is taken as the calibration value in this case. Other mid-frequency generators produce waveforms that are not so readily interpretable. Methods for interpretation of these waveforms have not been clearly defined.

5.3.2 Exposure Timer

The generator should be capable of terminating the exposure after a preselected time interval. Single-phase units may only be capable of terminating an exposure in increments of 8.3 msec (assuming a 60 hertz power source). Three-phase and mid-frequency generators should be capable of accurately terminating the exposure after 2 msec and at virtually any time interval thereafter (forced extinction). For generators that display the selected time prior to the exposure, accuracy should be within ±5% (for times greater than 10 msec) and ±10% for times less than 10 msec. Reproducibility of the exposure time should be within a coefficient of variation <0.05.[11]

Some generators indicate only the mAs of the exposure. This may imply a fixed mA or falling load operation. For fixed load operation, it may be possible to calculate exposure time from the mAs selected and the specifications of the generator (tube current must be known). Some manufacturers offer a selection of power levels (typically 100%, 80%, and 50% of rated maximum power) at each mAs selection that corresponds to short, medium, and long exposure times. Timer accuracy tests on generators with mAs-only type indicators are only necessary during acceptance testing.

5.3.3 Beam Quantity (mR/mAs)

The radiation output in milli-roentgens (mR) per milli-ampere second (mAs) can aid in the preparation of manual technique charts and in the calculation of patient exposure. Constancy of Beam Quantity with varying mA is indicative of the tube current calibration when minor fluctuations in kV are simultaneously monitored and appropriate corrections made. For constant load generators, the operating mA will depend upon the selected kV and the power rating of the tube or generator and may not be indicated on the control console. Beam quantity at adjacent mA stations is required to be within ±20% under federal law.[11] The output should also be reproducible to within a coefficient of variation of <0.10.[11] Since this quantity is indicative of proper tube current calibration, it is the task group's recommendation that the mR/mAs for all tube current settings on any given focal spot at any voltage setting be constant across the entire range of tube current settings available for that focal spot to within ±20%. Fluctuations in kV should be monitored and corrected for.

Radiation output should be characterized at a variety of kV and mA settings that encompass the useful range of the system on both focal spots. Documentation of the measured output should include the indicated kV, mA, focal spot size, and field size setting (L, W, and SID), as well as the distance from the source to the point of measurement and the measured kV.[21] From these data, patient entrance skin exposures should be calculated for those procedures most commonly performed in the room.

Radiation output waveforms can reveal information concerning the operation of the unit which is otherwise unavailable. The shape of the radiation pulse represents a combination of the tube voltage and current pulse shapes. The measurement requires the use of a radiation detector in the beam connected to an oscilloscope or digital capture device for display.

Beam quantity (mR/mAs) at a specified distance varies as a function of tube voltage, tube voltage ripple, tube current, and total filtration. As a first approximation, beam quantity for single phase generators should be 4 ± 0.8 mR/mAs @ 80 kVp @ 100 cm SID with approximately 2.5 mm Al total filtration.[22] The specification does not apply to capacitor discharge units (see section 8.2.3). Beam quantity for all other types of generators (limited amount of voltage ripple) should be approximately 6 ± 1 mR/mAs @ 80 kVp @ 100 cm SID with approximately 2.5 mm Al total filtration.[22]

5.3.4 Automatic Exposure Control (AEC)

The AEC system should ideally provide constant optical density regardless of kV selected, mA selected, or patient thickness being imaged. An AEC device automatically terminates the exposure based upon the transmitted radiation detected by a radiation monitor placed either behind the grid or behind the image receptor. The detector signal is used to charge a capacitor until a calibrated reference voltage

is achieved at which time an exposure termination signal is generated. Depending upon the characteristics of the detector and the quality and sophistication of the AEC circuitry, the system capabilities will vary considerably.[18,23] The AEC system should be capable of correcting for detector and image receptor kV dependence, beam hardening, and reciprocity law failure at long exposure times. The reader is referred to AAPM Report No. 14[18] for a thorough explanation of AEC devices and performance concepts.

The following items should be evaluated annually.

AEC Detector Selection. The indicators should accurately reflect which detectors are active.

Post-Reading mAs Indicator. This indication should be present and accurate.

Tracking. The response of the AEC system for varying kV, mA, and phantom thickness should be characterized. Routine radiographic systems should be capable of maintaining an optical density (OD) of about 1.0 ± 0.3 above base plus fog (nonmammographic systems only) over the clinical range of operation. Chest radiographic systems should maintain about 1.5 ± 0.1 OD above base plus fog. kV, mA, and thickness combinations used for these tests should represent anticipated clinical conditions of operation.

Minimum response time. The minimum response time of the generator and AEC system should be determined and posted to avoid selection of inappropriate kV and mA combinations in clinical use.

Maximum exposure limit (backup time). Should be tested and compared with statutory requirements to limit accidental patient overexposure.

Screen-film combination selector. If present, it must correctly modify detector sensitivity to mach the speed of the intended image receptor.

AEC Density Control. The AEC Density Control should allow lighter and darker film densities in appropriate intervals (approximately 0.15 to 0.30 OD/step) under clinical kV, mA, and thickness conditions.

AEC detector location. The indicators should properly mark the position of each detector. This item should be evaluated at acceptance testing and does not necessarily require annual testing (see section 1).

5.4 Grids

The performance of the grid needs to be checked at least annually (see section 1).

5.4.1 Artifacts

Grids should be radiographed to reveal any artifacts that could obscure patient information. This should be performed quarterly for grids used in portable operations, annually for auxiliary grids in radiography rooms, and during acceptance

testing only for grids that are permanently installed in Bucky devices (see section 1, **The Quality Control Process**). Grid reciprocation in Bucky assemblies should be confirmed at least annually.

5.4.2 X-ray Beam – Grid Alignment and Timing

X-ray beam misalignment with the grid in either of two dimensions may result in objectionable cut-off artifact, light films, and increased radiation exposure to the patient. Timing between the grid motion and the duration of the exposure may also cause grid artifacts and light films. The central ray of the x-ray beam should be normal to the plane of the grid and should be located in the center of the x-ray field. Wall Buckys and cassette holders that are susceptible to collisions with stretchers and doors may need to be tested more frequently (semiannually or quarterly). Severity of effects, and hence tolerable misalignment, will vary with the ratio of the grid in use and the system SID.

5.5 Electrical Safety

Leakage protection and absence of electrical shock hazards should be evaluated by qualified biomedical personnel prior to first patient use and annually thereafter.

6 QUALITY CONTROL OF FILM-SCREEN MAMMOGRAPHIC SYSTEMS

For any facility conducting screen-film mammography the federal government currently requires accreditation by an approved body with QC standards equivalent to those described in the ACR Mammography Accreditation Program (MAP) manual.[6] The Task Group feels that the QC guidelines that have been implemented by the ACR are more than sufficient to ensure adequate image quality, acceptable patient dose, and proper operation of mammographic equipment on an ongoing basis. Therefore, QC recommendations regarding mammography will not be addressed in this document. The practicing diagnostic medical physicist should be thoroughly familiar with the requirements of the ACR's Mammography Accreditation Program and the pertinent Mammography Quality Standards Act (MQSA) requirements.

7 QUALITY CONTROL OF CONVENTIONAL TOMOGRAPHY UNITS

Conventional tomography systems produce images in which much of the anatomy is intentionally blurred out of focus by moving the tube and image receptor in pre-determined paths. The anatomy of interest is not blurred in this fashion

and is preserved in a sharply focused image against a background of blurred overlying and underlying structures. The generator used to produce the radiation must be capable of producing low-intensity pulses of radiation over fairly long exposure times (0.5 sec at 100 mA to 5 sec at 10 mA). Most generators for routine radiography are not calibrated at these extremely low mA stations in spite of the fact that conventional tomography capability has been included. Careful attention must be paid to operation at these low mA settings when evaluating generator performance in conventional tomography. At the same time, these units are usually utilized as conventional radiographic systems as well. Performance at conventional techniques must also be evaluated.

The performance parameters to be tested are identical to those listed in section 5 of this document, **Quality Control of Radiographic Units**.[25,26] In addition, the following items should be evaluated **annually**.

7.1 Motion

The motion of the x-ray tube–Bucky assembly should be evaluated for correctness of motion and stability during movement. In particular, the movement of the Bucky assembly should be smooth relative to the motion of the x-ray tube. As the system ages, it may become necessary to evaluate the motion stability more frequently to maintain acceptable performance.

7.2 Tomographic Exposure Angle Accuracy

Tomographic exposure angles should be within ±20% of the indicated exposure angle. The exposure sweep should be symmetric to the centered normal of the imaging plane.

7.3 System Spatial Resolution

Under high-contrast conditions, the system should be capable of resolving a #40 mesh brass or copper screen positioned in the tomographic plane.

7.4 Accuracy of Cut Level

The accuracy of the “cut level” indicator or selector should be within ±3 mm.

7.5 Section Thickness

Section thickness should be measured for each clinically used angle and motion.

In many cases, repeated exposures to cover a large anatomical volume with thin sections are necessary. As a result, the anode and housing thermal characteristics

may become critical in selection of a tube for conventional tomography. An external cooling fan mounted on the tube housing assembly is recommended for high-workload situations and during extensive QC testing.

8 QUALITY CONTROL OF PORTABLE X-RAY SYSTEMS

The mobile radiographic (portable) unit is designed for ruggedness and simplicity. Only one mA station and one focal spot size may be available on portable units. Whenever possible, the same tests that are performed on a fixed radiographic unit should be performed on a portable unit. The unit must be fully charged prior to testing. Testing may have to be performed in stages to allow the system to maintain a high level of charge throughout the test period. Particular attention should be given to the evaluation of mechanical components such as angulation indicators, SID indicators, beam localizer alignment, collimation indicators, and mechanical locks. These items are subject to unusual stress due to vibrations during transportation throughout the institution. Testing should be performed **semiannually** (see section 1).

8.1 High Frequency Systems

8.1.1 X-ray Tube and Generator

In high-frequency invertor-based systems, the radiographic operation of the system may be evaluated as with any other radiographic unit. Refer to the appropriate section of this document for recommendations on QC of radiographic tubes and generators (sections 5.2 and 5.3).

8.1.2 Radiation Output During Extended Use

The mR/mAs output should be determined when the unit is fully charged and again after it has been driven for a distance comparable to what would be expected in clinical use. Radiation output should decrease by no more that 20% under these conditions.

8.2 Capacitive Discharge Systems

8.2.1 kV Calibration

Since the kV is constantly changing during the exposure, an oscilloscope is required to monitor the kV drop during each exposure. kV should drop by no more than 1 kVp per mAs over the entire exposure. Excessive drop is indicative of a leaking capacitor network.

8.2.2 Leakage Radiation

In some designs, there may be voltage applied across the tube during standby and prep. In this case, the housing will include a shutter mechanism designed to block any radiation generated prior to initiation of exposure. Proper performance of this device must be confirmed to protect patients and staff from inadvertent exposure.

8.2.3 Beam Quantity

Since the kV is constantly changing during the exposure, radiation output will not maintain linearity between mAs stations. Beam quantity should be characterized for several mAs stations at several kV settings each, encompassing the clinically useful range, at least annually. Results may then be evaluated for constancy.

8.3 Additional Tests

Additional tests need to be performed annually on all systems including testing of brakes, visual inspections of protective bumpers, drive speed control, and correct functionality of the Forward/Reverse switch.

9 QUALITY CONTROL OF FLUOROSCOPIC EQUIPMENT

Fluoroscopy is the leading contributor of exposure to the U.S. population from medical imaging. In 1995 the Food and Drug Administration (FDA) issued an advisory cautioning against the excessive use of high dose rate (HDR) fluoroscopy. There have been several documented cases of patients receiving burns from these units.[27] It is therefore important to evaluate, on an ongoing basis, both the quality of the fluoroscopic images and the exposure output of the fluoroscopic system. In addition, the JCAHO[28] requires that entrance exposure data be measured in order that patient doses can be accurately determined when the need arises.

Fluoroscopic systems are part of the core imaging systems in the radiology department. Because they are used for many critical examination types such as interventional radiography and angiography, these relatively fragile systems should receive a great deal of attention in any complete quality assurance program. In many instances it would be appropriate to enlist the cooperation of the technologists who use the fluoroscopic rooms in the department as an integral part of the QC program.

9.1 Daily

Daily measurements of fluoroscopic systems are not necessary except under special circumstances. For example, if the radiologists are complaining of intermittent problems relating to resolution or noise, daily measurements for a short

period may help isolate the nature of the problem. Suitable phantoms for daily evaluation of fluoroscopic image quality and system performance are described in the literature[28] and available commercially.

Hard Copy. System contrast transfer function should be checked for stability in accordance with section 16.1, **Hard-Copy Device**.

9.2 Monthly or More Frequently if Indicated

System Function. A periodic check of the fluoroscopic system by the technologists who use the room on a daily basis is appropriate. Evaluation of spatial resolution and contrast resolution using a simple phantom (consisting of an attenuator, a wire mesh phantom, and a step-wedge) are important. Problems that can arise with the fluoroscopic system between the evaluations by the medical physicist may be identified during these periodic audits. The operator may track kV and mA required to produce an acceptable image as an index of system stability. The step-wedge may also be used as a daily check on monitor brightness and contrast settings.

9.3 Fluoroscopic Mode: Tested Annually or More Frequently If Indicated

9.3.1 Typical Exposure Rates

The entrance exposure rate including backscatter for a "typical" patient should be evaluated at least annually. In some regulatory environments, more frequent (i.e., quarterly or monthly) evaluation may be required. This measurement requires the system to be set up in the same geometric configuration as it is used for typical patient examinations, using automatic brightness control mode.[30,31,32] This usually involves placing thicknesses of PMMA (polymethylmethacrylate or "acrylic") or another tissue-mimicking attenuator[29] (10, 20, and 30 cm thicknesses are recommended) in the beam, and measuring the exposure between the x-ray tube and the entrance of the PMMA. The Automatic Brightness Control (ABC) system should be activated, and operated in a typical clinical mode. The determination should be made in all available magnification modes. A radiotransparent dosimeter is required for these measurements to avoid interference with the ABC system. If a free-in-air measurement is desired, a phantom material other than PMMA is required unless the geometry of the measurement can be altered to accommodate the necessary air gap.

For portable C-arm systems and for C-arm or U-arm systems, the tabletop exposure is not appropriate since these systems allow lateral exposure to the patient, without attenuation of the beam due to the table. With the SID set at 100 cm, the ionization chamber should be placed at 30 cm in front of the input to the imaging

assembly for entrance exposure rates including backscatter. If a free-in-air measurement is desired, the ionization chamber should be placed 50 cm (20 in.) from the front surface of the imaging assembly to create an air gap between the phantom and ionization chamber. With the phantom in front of the image intensifier, the exposure rate is recorded, and the inverse-square law is used to calculate the entrance skin exposure at 30 cm in front of the input to the imaging assembly.

If the system is typically operated in a lateral mode with a separate AP/PA (antero-posterior/postero-anterior) imaging chain, the scattering phantom should be centered at the midpoint of the SID with the ionization chamber placed between the x-ray tube and the phantom. This geometry measures entrance exposure with or without backscatter dependent on the presence or absence of an air gap between the ionization chamber and phantom entrance surface. The entrance skin exposure should be calculated at a point 15 cm toward the x-ray focal spot from the midpoint of the SID.

If the system is capable of HDR fluoroscopy, the typical exposure values should be determined for this mode(s) of operation as well.

9.3.2 Maximum Exposure Rates

The maximum patient exposure rate should be evaluated without backscatter; a PMMA scattering phantom should not be used. The maximum exposure rate should be determined by placing a sheet of lead over the input of the image intensifier, which causes the ABC circuitry to produce a maximum exposure rate. The image on the monitor should be blank, assuring that the ABC is driving the kV and mA to their maximum values. The exposure rate should be measured at the tabletop for under-table x-ray tube systems. If it is possible to adjust the distance between the x-ray focal spot and tabletop, this distance should be minimized.

Federal regulations concerning maximum patient exposure rates during fluoroscopy are somewhat complex due to the variety of operational modes provided by equipment manufacturers. To further complicate the issue, these rules were rewritten in 1994 due to concern over the potential for occult patient injury during HDR fluoroscopy when used in combination with cineradiography or Digital Subtraction Angiography (DSA).[27] In concert with the new regulations, the AAPM recommends that all fluoroscopy systems be limited to 10 R/min during normal operation and to 20 R/min in HDR regardless of the date of manufacture of the system.

For portable C-arm systems, and for C-arm or U-arm systems, the tabletop exposure measurement is not appropriate since these systems allow lateral exposure to the patient, without attenuation of the beam due to the table. With the SID set at the minimum, the exposure meter should be placed 30 cm (12 in.) from the front surface of the imaging assembly. With the lead sheet in front of the image intensifier, the maximum exposure rate is recorded.

If the system is capable of HDR fluoroscopy, the maximum exposure values should be determined for this mode(s) of operation as well.

9.3.3 Image Quality

Image quality in fluoroscopy should be determined for two characteristics of the system, spatial resolution and contrast resolution.[31,32]

Spatial resolution. Spatial resolution of the system should be determined by taping a line pair phantom to the center of the front surface of the image intensifier. The line pairs can be positioned 45 degrees with respect to the video scan lines and grid lines. Typically, a line pair phantom with the range of 0.7 line pairs per mm (c/mm) to 5 c/mm is used. With a copper plate (0.8 to 1.2 mm thick) placed in the beam at the collimator, the line pair corresponding to the highest spatial frequency that is visible under ABC-controlled fluoroscopy should be recorded. Both theoretical and achievable measured spatial resolution values have been published.[33] It is important that the same individual be responsible for this test from time to time, to reduce the degree of subjective error. If multiple television monitors exist, the one used most by the radiologist during fluoroscopic studies should be used to make the measurement. Other monitors may be tested as well to identify monitor problems.

Contrast resolution. Contrast resolution is determined by viewing a phantom containing various objects that span a range of subtle contrasts. The preferred phantoms for determining fluoroscopic contrast resolution are either the University of Alabama – Birmingham (UAB)[34] phantom or the Leeds[35] phantom. These phantoms consist of metal blocks or plates with holes of different depths bored into them. The systems have been calibrated at various kVs. The visual observation is made, and the kV recorded. With the calibration information, the absolute contrast resolution can be determined. A fluoroscopic system in good repair should resolve 11 mm discs at a contrast level <2%.[36]

9.4 Radiographic Mode: Tested Annually or More Frequently If Indicated

In many radiographic-fluoroscopic systems, the radiographic (spot film) circuit is independent of the fluoroscopic circuit, and should therefore be evaluated separately. Refer to sections 5.2.1 and 5.3 for information recommendations on QC of radiographic generators.

9.4.1 Kilovoltage Calibration

In fluoroscopy the kV may be continuously changing as a result of the automatic brightness control. For most systems, there is very little need to know whether the kV is accurate or not, since this knowledge will affect neither the image quality nor the dose to the patient in a direct sense. The easiest way to determine fluoroscopic kV is to use a noninvasive kV meter. These devices are commercially available, and, if carefully selected, simple to operate. The kV meter is

placed in the fluoroscopic beam, and the kV is read out. kV indicators should be accurate to ±10%.

9.4.2 Radiation Quality (HVL)

The fluoroscopic circuitry in the x-ray generator is different from the radiographic circuitry, so radiographic beam quality results do not apply to the fluoroscopy capabilities of the unit. For fluoroscopic systems with manual kV control override, the preferred method for determining the HVL is to set the kV, and determine the HVL just as one would for a radiographic unit, measuring exposure rate instead of exposure. When a manual kV setting is not available on the fluoroscopic system, the HVL will have to be measured in ABC mode. To accomplish this, the field of view is minimized, and the exposure probe is placed as far away from the x-ray tube as possible. Several 1-mm sheets of aluminum are placed between the probe and the image intensifier. The sheets need to be big enough to span the minimized field of view and there needs to be enough of them to drive the kV to at least 80 kVp. The exposure rate is measured, and a single sheet of aluminum is removed from the stack behind the chamber and placed in front of the chamber midway between the x-ray tube and the probe. Again, the exposure rate is measured, and the next filter is moved, and so on. This procedure keeps the same amount of aluminum in the beam for each measurement while varying the filtration in front of the probe. The ABC should be holding a constant mA and kV. In practice, knowing the HVL without knowing the kV is not that valuable, and so the kV reported by the fluoroscopic kV indicator on the system should be recorded. If the x-ray system does not have a kV indicator, there is no value in determining the HVL other than to assure compliance with state regulations.

9.4.3 X-ray Anti-Scatter Grid

The grid can become dented or positioned incorrectly in the system with clinical usage. If possible, the x-ray grid should be removed from the system and radiographed using a detail screen-film system.

9.4.4 Collimation

Confinement of the x-ray field to the image receptor (in both fluoroscopic and radiographic modes) should be verified.

Spot-film collimation. In radiographic mode the central ray of the x-ray beam should be aligned with the center of the image receptor, when placed in the Bucky, to prevent image cut-off and to avoid radiating tissues unnecessarily. Federal regulations[11] currently require that the edges of the x-ray fields and corresponding image receptor edges agree to within ±3% of the SID. Tests should be performed at least annually or as often as necessary to maintain correct alignment. Further, the sum total of the misalignment in the X and Y dimensions should be less than

4% of the SID. Tests should be performed for enough image receptor formats to test each collimator blade position available. Older systems usually require more frequent evaluation (see section 1).

Fluoroscopic collimation. In fluoroscopic mode the central ray of the x-ray beam should be aligned with the center of the video image to prevent image cut-off and to avoid radiating tissues unnecessarily. Federal regulations[11] currently require that the edges of the x-ray fields and corresponding image receptor edges agree to within ±2% of the SID. Tests should be performed in all II magnification modes. Older systems usually require more frequent evaluation (see section 1).

9.4.5 Image Intensifier Input Exposure Rate (IIIER)

The IIIER, which is set by the service engineer during calibration of the system, has a direct effect on the entrance exposure rate to the patient. When the IIIER is set properly, the compromise between image noise and patient dose is such that diagnostic quality is delivered at the lowest possible radiation dose. A proper IIIER setting also ensures that the typical patient entrance exposures will be reduced to the minimum exposure appropriate for the patient's size. With standard aluminum filtration added to the x-ray beam, IIIER values in the range of 1.5 to 2.5 μR per fluoroscopic video frame are typically set.[38] A discussion of the numerous design parameters and factors that affect the appropriate IIIER values has been previously published.[37,38]

The measurement is made with the machine set up in its typical clinical geometry and the ionization chamber between the grid and the entrance plane of the image intensifier using the ABC mode. An attenuator thick enough to drive the kV to 75 to 85 kVp is placed on the tabletop for each measurement. IIIERs should be measured as a function of the following variables:

- Each magnification mode of the image intensifier
- Each IIIER setting the machine provides
- Each pulsed fluoroscopy frame rate

In addition to the above variables, most units have multiple modes of operation. IIIERs for all the following modes of operation that are available on the machine should be checked:

- Continuous fluoroscopy (analog, digital)
- Pulsed fluoroscopy (analog, digital)
- Any "high level" fluoroscopy mode
- Setup test exposure mode

The shape of the ionization chamber or the design of the imaging system may not allow the medical physicist to place the ionization chamber at the entrance plane of the image intensifier behind the grid. In this case, the machine can be set up in its clinically used geometry and operated in the ABC mode with the appropriate

phantom in place to determine the clinical kV, mA, and pulse width for the mode of operation. After recording these technique factors, the image intensifier can be moved to its maximum distance from the focal spot. The ionization chamber is placed "free-in-air" in the x-ray beam at the distance where the entrance plane of the image intensifier was located during the determination of clinical technique factors. The machine is placed in the manual mode which allows the operator to set the previously determined clinical technique factors. The exposure is recorded and corrected for the attenuation factor of the grid to determine the IIIER.

9.5 Acceptance Testing

Prior to first clinical use of the equipment, all QC tests, sections 9.2 through 9.4, should be completed. In addition, the focal spot size should be measured according to section 5.2.6.

10 QUALITY CONTROL FOR DIGITAL SUBTRACTION ANGIOGRAPHY (DSA) SYSTEMS

Quality assurance in DSA requires the participation of someone who knows how to operate the DSA system. For the medical physicist, this can sometimes be a time-consuming learning experience. Alternately, the medical physicist can work with a technologist who knows the system well. For a general introduction to DSA systems and performance measurements, the reader is referred to AAPM Report No. 15.[39]

10.1 Daily

A phantom image should be acquired before each clinical day commences. This should be the technologist's responsibility and can be done at the same time that the tube is warmed up in the morning. The phantom should contain templates which reveal aspects of both spatial and contrast resolution. The images should be subtracted, and recorded each day on film.

Hard Copy. System contrast transfer function should be checked for stability in accordance with section 16.1.

10.2 Annually or More Frequently If Indicated

10.2.1 Fluoroscopic System Evaluation

Perform all tests listed in sections 9.2 and 9.3.

10.2.2 Radiographic System Evaluation

Perform all test listed in section 9.4.

10.2.2.1 **Expected IIIER digital angiographic values.** Using the test methods outlined in section 9.4.5, one expects <100 μR/image measured IIIER at 80 kVp with the grid removed.[37]

10.2.2.2 **Expected IIIER digital subtraction angiographic values.** Using the test methods outlined in section 9.4.5, one expects <100 μR/image measured IIIER at 80 kVp with the grid removed.[37]

10.2.3 Spatial Resolution

Spatial resolution in DSA should be determined using a bar phantom template with spatial frequencies spanning the range from 0.6 c/mm to 5.0 c/mm. The vertical and horizontal spatial limiting resolutions should be evaluated separately, in each image intensifier mode. Also, if the DSA system has different pixel matrix capabilities, for example 512×512 and 1024×1024 acquisition, each of these should also be evaluated.

10.2.4 Contrast Resolution

The aluminum hole phantom used commonly in fluoroscopic system analysis may be adequate to determine contrast resolution in DSA. However, since the contrast of interest in DSA is always produced by iodinated contrast media, it is worthwhile to evaluate contrast with a phantom that more closely mimics iodine contrast. Contrast agent itself can be used, however solutions in liquid form are not stable and the iodine-bound molecules will precipitate out of solution over a period of a month or so. For an annual evaluation, it may be appropriate to mix up some solutions for testing. The solutions should span a range of contrasts, for example a mixture of 0.5% to 3% contrast agent (370 mg/ml, percent by volume) and water. A standard thickness such as 1 cm could be used. Commercially produced phantoms containing stabilized iodine contrast agent are available as well.

Contrast resolution in fluoroscopy usually involves a subjective determination of the contrast of a phantom. With DSA, however, the determination can be quantitative, since digital images are generated. A phantom with a range of contrasts is imaged, and the software in the system is used to determine the mean and standard deviation of regions of interest (ROIs) on the subtracted image. The contrast resolution can then be displayed graphically as a scatter plot of digital number versus absolute iodine concentration. Using linear regression, the slope of the graph can be determined and this is a convenient parameter which describes the contrast resolution of the system. Its units are digital number (i.e., contrast) per iodine concentration.

Contrast resolution can vary for different image matrices and image intensifier magnification modes, and therefore should be determined for each unique combination of these variables when a thorough evaluation of the system is warranted.

10.2.5 Detector Sensitivity

For conventional, video-based systems, the detector sensitivity in DSA, unlike film-screen systems, may be regulated by changing the size of the light-limiting aperture in the optical coupling between the output of the image intensifier and the DSA camera. The size of the aperture, in combination with the gain of the image intensifier, determines the overall sensitivity (speed) of the imaging chain. The speed of the imaging chain directly affects the amount of quantum noise in the resulting image and inversely affects the patient dose. Detector sensitivity is evaluated by measuring the typical exposure rate per frame at the image intensifier input phosphor.

In charged-couple device (CCD)-based digital systems that use a fiber-optic taper instead of a lens, speed is fixed. Speed should be determined for these systems as well, but remedial action may not be easily achievable.

Most DSA systems run the digital signal through a logarithmic look-up table (LUT) in real time. If the system allows setting the acquisition LUT to a linear function, this should be done. With the aperture set as it is in clinical usage, the characteristic curve of the DSA system should be evaluated if possible. A large chamber (pancake) exposure meter is positioned at the input face of the image intensifier, and a series of manually exposed images are acquired. The radiation exposure is also recorded. The mean gray scale value in the unsubtracted images is determined using system software at the ROI at the center of the pancake chamber. The characteristic curve is simply a plot of the digital number versus exposure. The speed of the system should be determined at the middle gray scale value (for a linear input look-up table). For an 8-bit image (256 shades of gray), the speed should be calculated at a gray scale value of 128 (just like the speed of a screen-film system is calculated at an optical density of 1.0 above base plus fog). The exposure at this point on the curve is read in roentgens, and that value is inverted (divided into unity) to calculate the speed in units of R^{-1}. A typical value for the speed of DSA systems is 1000 R^{-1} (1 mR per frame).

10.3 At Acceptance and as Needed

The *characteristic curve* should be evaluated at acceptance testing, whenever camera or ABC settings are made, or when problems occur with the system. If a variety of aperture sizes are available and are used clinically on the system, it would be wise to determine the characteristic curve (and the speed) of the system as a function of aperture setting. With a linear LUT, the characteristic curve with a Plumbicon should be very close to linear. If the camera is incorrectly set up, deviations from linearity may be observed. Furthermore, the digital numbers should span the entire range of possible numbers. For an 8-bit system, the no-exposure (lead over the x-ray tube) value should be small, between 4 and 10. The maximum number should saturate close to 255. If the entire dynamic range of the system is not utilized, the system is in need

of service. The gain, offset, and peak white clipping settings of the analog-to-digital converter need to be adjusted to maximize the usable dynamic range of the system.

11 QUALITY CONTROL OF CINERADIOGRAPHY SYSTEMS

Cine (cineradiography) systems used for cardiac angiography contribute some of the highest radiation exposures to patients in the entire field of medical imaging. With the development of x-ray tubes in recent years with increased kW ratings, many new systems are capable of generating maximum entrance exposure rates during cine in excess of 200 to 300 R/min to the patient. It is imperative that patient exposures and image quality associated with this equipment are monitored on an ongoing basis.

The AAPM has recently published Report No. 70[36] of Task Group No. 17, Diagnostic X-Ray Imaging Committee, on quality control of cine systems. The information in this section is consistent with the recommendations of that report.

A cine system consists of a fluoroscopic television chain with an attached 35 mm cine camera designed to record images at up to 90 frames per second. Since heart wall motion during peak systole can reach 200 mm/sec, the system is designed to minimize motion artifact. Thus, cine quality assurance measurements build on the basic tests found in section 9 (**Quality Control of Fluoroscopic Equipment**). The additional tests described in this section address the ability of the system to improve temporal resolution and other unique features of the cine system.[40]

11.1 Daily

11.1.1 System Status Check

A phantom taped to the entrance plane of the image intensifier should be recorded on cine film at the beginning of each case. Depending on the design of the phantom, 1 mm of copper may need to be added at the tabletop or on the face of the collimator. Since the technologist must record the name of the patient on the cine film prior to beginning the case, a “name area” can be incorporated into the quality assurance phantom. This ensures that QC data are recorded on film for each patient. While these data may not be evaluated on a daily basis, they are available for weekly analysis and to assist the medical physicist in identifying the cause of the cardiologist’s complaints concerning intermittent problems. These data also can be helpful when processor problems occur.

The center of the phantom should contain a lead line pair phantom with an equivalent lead thickness of 0.1 mm and a range of spatial frequencies from 0.6 to 5 c/mm to allow measurement of the spatial resolution of the system. The phantom should be oriented with the long axis of the lead pattern at a 45-degree angle

with respect to the television (TV) lines and grid lines. Discs approximately 1 cm in diameter of varying thicknesses (yielding various contrast levels) with their centers the same distance from the center of the phantom should be built into a phantom to allow determination of contrast resolution. Two test objects which produce a contrast level change of approximately 5%, one at the "black" and one at the "white" end of the video output signal should be included; these are used to check the proper setting of the "brightness" and "contrast" on the TV monitors in the system.

11.1.2 Processor

The sensitometric properties of the processor should be evaluated (see section 13, **Quality Control for Darkrooms, Processors, Film, and Cassettes**).

11.2 Weekly

On a weekly basis for each imaging system, the results of the phantom images should be evaluated by the Quality Control Technologist and reviewed by the medical physicist. This involves measuring the spatial resolution, low contrast resolution, and density level on the processed cine film.

During cine recording, fluoroscopy should be initiated to allow the correct setting of the "brightness" and "contrast" on any TV monitor with adjustable knobs for these settings. In addition, during fluoroscopy, the spatial resolution and contrast resolution should be noted and *recorded*.

11.3 Semiannually

11.3.1 The Typical and Maximum Exposure Rates

Semiannually or each time an x-ray tube is changed, whichever occurs first, the typical and maximum exposure rates to the patient during all modes of fluoroscopy should be measured by the medical physicist as described in section 9 (**Quality Control of Fluoroscopic Equipment**). Checking these exposure rates twice a year should be sufficient provided more frequent phantom analysis is completed as described in the weekly section above. Cine systems may have all the following fluoroscopic modes of operation that need to be monitored:

- Continuous fluoroscopy (analog, digital)
- Pulsed fluoroscopy (analog, digital)
- Any "high level" fluoroscopy mode

If any of these entrance exposure rates to the patient exceed 20 R/min, the corresponding entrance exposure rates to the input of the image intensifier (see section 9) should be measured and adjusted.

11.3.2 Projection System

Cine projectors should be cleaned and adjusted as required. All accessible lenses and optical surfaces should be cleaned according to the manufacturer's recommendations. Worn, scratched, or damaged parts should be replaced. The proper transport of film through the unit should be verified (no jitter, etc.). Test strips of cine film containing appropriate test patterns [such as the Society of Motion Picture & Television Engineers (SMPTE) pattern] should be projected to evaluate focus, resolution, and distortion of the projected image.

11.4 Annually

At least once a year the entire imaging chain including the projection system should be cleaned and recalibrated by service personnel. This involves at a minimum the calibration of the following:

- Image intensifier
- Focus of various lens systems
- TV camera
- Cine camera
- Calibration of TV system including minimization of lag
- Density level on cine film

After the above adjustments are complete, the following should be measured by the medical physicist. The medical physicist may need some assistance from service personnel to complete some of the measurements. All the data described in this section should be recorded. This recorded data becomes the standard against which the subsequent data collected weekly will be compared.[2]

11.4.1 Monitor Adjustment

See **Weekly** section (section 11.2) for discussion of phantom and check of proper setting of each monitor's "brightness" and "contrast" controls.

11.4.2 Spatial Resolution

The phantom used for the "Daily" recordings on film can be used for these checks. Spatial resolution at the output of the image intensifier, at the television monitor, and on the cine film should be measured to ensure that the focus of each component is optimized.

11.4.3 Contrast Resolution

The "Daily" phantom can be used to measure contrast resolution on all monitors.

11.4.4 TV Camera Lag

Tests should be completed to verify that the frame-to-frame persistence of the video does not result in unnecessary smearing of moving objects within the fluoroscopic image. This is most easily confirmed by using a commercially available plastic disc that spins at 30 rpm. The disc contains six different gauges of piano wire and lead shot. The lead shot moves at approximately 180 mm/sec and provides a high-contrast object that can be used to measure image persistence. This phantom is used in conjunction with a large polypropylene container in which 15, 20, or 25 cm of water is placed to create clinical levels of contrast and noise.

11.4.5 Film Density

The optical density of the background of the "Daily" phantom image on cine film should be measured.

11.4.6 Typical and Maximum Exposure Rates to Patient

See **Semiannual** section above (section 11.3).

11.4.7 Generator Calibration

The generator may have three different modes of operation: continuous fluoroscopic, pulsed fluoroscopic, and pulsed cine. Typical ranges for continuous fluoroscopy are 50 to 120 kVp and 0.1 to 3 mA. Pulsed fluoroscopic ranges are 50 to 120 kVp, 10 to 100 mA, and 1 to 10 msec pulse width. Ranges of 50 to 120 kVp, 100 to 1000 mA, and 1 to 8 msec pulse width are routinely encountered during cine recording. Unless the medical physicist has specific design information to the contrary, he/she should assume each of the above modes of operation involve unique control circuitry in the generator. Each of the three modes should be evaluated separately.

Continuous Fluoroscopic Mode. See section 9, **Quality Control of Fluoroscopic Equipment**.

Pulsed Fluoroscopic Mode. Although the importance of the accuracy of kV and tube current during pulsed fluoroscopy is somewhat controversial (see section 9) the accuracy (agreement between actual value and indicated value) should be checked to ensure that the generator is performing properly and the x-ray tube is not overloaded by the ABC system of the generator. Fluoroscopic kV should be accurate to within ±10%.

Pulsed Cine Mode. All three parameters, kV, mA, and pulse width, should be carefully checked in the pulsed cine mode. The pulse width calibration is important as previously discussed under the section on pulsed fluoroscopy. While the kV and mA calibrations do not directly affect the image quality or patient dose,

large errors must be avoided to prevent equipment damage or loss of image quality. The indicated kV and mA are typically the largest values allowed by the limited loading of the x-ray tube. If the actual mA is less than the indicated mA, the x-ray tube is not fully loaded. This will cause the generator to increase kV to deliver the proper exposure rate at the entrance plane of the image intensifier. This results in a higher kV, which increases scatter and reduces subject contrast resulting in a loss of image contrast. If the actual kV or mA is greater than the indicated values, the x-ray tube could be damaged by excessive heat loading.

Waveforms and timing. Since appropriate noninvasive devices for tube current do not exist, the medical physicist may wish to monitor the calibration procedure and results of the service representative during calibration. Care should be taken to protect the imaging assembly from repeated high intensity exposure during this phase of testing by intercepting the beam with lead before it strikes the input phosphor.

Several pulse shapes are available for monitoring by the medical physicist. The kV and radiation pulse shapes are the most convenient to acquire (mA pulses require invasive techniques). These, however, may be under software control during cine, rendering their evaluation difficult at best. The manufacturer's representative should be consulted concerning proper evaluation of pulse shapes. Minimally, these pulses should be checked for duration of the width and timing with the imaging chain. The pulse width, if excessive, can result in significant loss of image quality due to motion unsharpness. If the capacitive tail of the kV waveform is excessively long, it may lengthen the effective pulse width. This not only further degrades image quality, but also eliminates much of the dose-saving features of pulsed fluoroscopy. Pulse timing must be properly coordinated with the image recording system to assure that no exposure is produced between frames. This minimizes patient dose and reduces image blur. Any noninvasive kV meter used for these measurements must be capable of responding accurately to a pulsed beam of radiation at up to 90 pulses/second with pulse duration on the order of a millisecond.

11.4.8 Image Intensifier Input Exposure Rate (IIIER)

The IIIER, which is set by the service engineer during calibration of the system, has a direct effect on the entrance exposure rate to the patient. When the IIIER is set properly, the compromise between image noise and patient dose is such that diagnostic quality is delivered at the lowest possible radiation dose. A proper IIIER setting also ensures that the typical patient entrance exposures will be reduced to the minimum exposure appropriate for the patient's size.

The measurement is made with the machine set up in its typical clinical geometry and the ionization chamber between the grid and the entrance plane of the image intensifier using the ABC mode. A tissue-mimicking attenuator thick enough to drive the kV to 75 to 85 kVp is placed on the tabletop for each measurement. IIIERs should be measured as a function of the following variables:

- Each magnification mode of the image intensifier
- Each IIIER setting the machine provides
- Each pulsed fluoroscopy frame rate

In addition to the above variables, most units have multiple modes of operation. IIIERs for all the following modes of operation that are available on the machine should be checked:

- Continuous fluoroscopy (analog, digital)
- Pulsed fluoroscopy (analog, digital)
- Any "high level" fluoroscopy mode
- Setup test exposure mode

In recording modes of the cine machine (cine, digital record modes, etc.), the image intensifier input exposure per pulse of radiation (IIIEP) should also be measured and changed if appropriate.

The shape of the ionization chamber or the design of the imaging system may not allow the medical physicist to place the ionization chamber at the entrance plane of the image intensifier behind the grid. In this case, the machine can be set up in its clinically used geometry and operated in the ABC mode with the appropriate phantom in place to determine the clinical kV, mA, and pulse width for the mode of operation. After recording these technique factors, the image intensifier can be moved to its maximum distance from the focal spot. The ionization chamber is placed "free-in-air" in the x-ray beam at the distance where the entrance plane of the image intensifier was located during the determination of clinical technique factors. The machine is placed in the manual mode, allowing the operator to set the previously determined clinical technique factors. The exposure is recorded and corrected for the Bucky factor of the grid to determine the IIIER.

11.4.9 Half Value Layer (HVL)

See section 9.4.2, **Radiation Quality (HVL)**.

12 QUALITY CONTROL OF COMPUTED TOMOGRAPHY SYSTEMS

With its introduction in 1972, computed tomography (CT) revolutionized radiology. From initial scan times of several minutes for a single slice from a conventional (axial) CT, scan times have been reduced to just seconds for full volume acquisitions using helical or "spiral" CT and slip ring technology[41,42] and to subsecond acquisitions for ultrafast electron beam CT scanners.[43,44] Great improvements in image quality have also been realized through faster and more efficient detectors. A resurgence in CT has been recently realized with the rapid acceptance of multiple row or "multislice" CT scanners. CT scanners in clinical use today are generally either of the third-generation type (both the x-ray source and detectors

rotate together) or of the fourth-generation type (the x-ray source rotates around the patient while the detectors remain fixed). Helical CT units are available in both third- and fourth-generation designs while most modern multislice CT units are third generation designs.

Many of the QA tests for conventional scanners (or helical and multislice units operating in the axial mode) can now be performed using testing phantoms and protocols designed by the manufacturers. One must be careful utilizing CT phantoms produced in the 1970s. Because of the improvement in CT image quality, these early phantoms may not provide the means for testing the imaging limits of present CT scanners. The results of all QA tests should be compared to any manufacturer's limiting values and to the results of acceptance testing.[2,45] For a general introduction to axial and single-slice helical CT scanners and performance measurements, the reader is referred to AAPM Report No. 39, "Specification and Acceptance Testing of Computed Tomography Scanners"[46] and to the 1995 AAPM Summer School Proceedings, *Medical CT & Ultrasound: Current Technology and Applications*.[47] An excellent discussion by Suess[48] regarding QC in single-slice helical CT is contained in the aforementioned proceedings. General descriptions of multislice systems and applications are also present in the literature.[49–57]

12.1 Daily

CT Number Accuracy of Water, Image Noise, Image Uniformity, and Artifacts. These tests are combined since they are all obtained from the same CT phantom scans. They also are the most critical tests to be performed on a CT scanner, since they are sensitive to a wide range of CT scanner problems. This test involves imaging a water-filled (or uniform, water equivalent) phantom and using the statistics function of the CT scanner to determine the average CT number and standard deviation of the image noise in a ROI in the image. The image is also inspected for any nonuniformities or artifacts. The test for nonuniformities may also be performed quantitatively by obtaining average CT numbers over different areas of the image, e.g., central and four outer areas. Artifacts include the presence of "ring artifacts" which can be caused by miscalibration of the detectors in a third generation CT scanner or extra-focal radiation from the tube of a fourth generation scanner. Nonuniformities include shading, or variations in the CT number over different parts of the phantom image. Examples are variations from one side of the phantom to the other and from the central to outer areas of the phantom.

These tests should be performed daily using at least one common technique setting with a "head sized" phantom, typically about 20 cm in diameter (see above). Analysis is simple and can be performed by the technologist operator. The average CT number and standard deviation of the noise should be obtained for a central region larger than 10×10 cm^2. The size of the ROI used should be standardized for the QA tests. The image should be inspected visually for image nonuniformities and artifacts using a suitable window level and window width. To properly

visualize nonuniformities and artifacts the window width should be relatively narrow, e.g., 50 to 100 Hounsfield units (HU). Use of excessively narrow window widths may enhance clinically insignificant artifacts. Significant artifacts or changes in mean CT number or standard deviation may be indicative of a malfunctioning system.

12.2 Semiannually or More Frequently If Indicated

More complete versions of the above tests should be performed on a monthly to semi-annual basis, depending upon available resources (see section 1). In these tests images should be obtained using at least two different phantom sizes (e.g., head, body). Images should be obtained at all slice thicknesses used clinically. It is important that artifact scans be obtained at very thin slices and also in helical modes if possible. If more than one kV and/or mA is used clinically, images should be obtained with those techniques. Images should also be obtained using different scan times and different reconstruction algorithms.

12.2.1 Imaged Slice Thickness (Slice Sensitivity Profile, SSP)

This test should be performed monthly to semiannually at all available slice thicknesses using an appropriate test phantom, such as aluminum or wire ramps for axial mode or a bead phantom for helical mode (see section 12.3.3 for details on helical SSP measurements). The imaged slice thickness is usually taken as the full width at half maximum (FWHM) of the slice profile.

12.2.2 Dose Profile Width

This test should be performed monthly to semiannually at all available slice thicknesses. One quick method uses a packaged film, placed on the phantom surface during scans at the different slice thicknesses. The film is moved between scans so that a different area is exposed. The mAs technique is set to provide a maximum film density of between 1.0 and 2.0 OD. Overexposure of the film must be avoided, since an incorrectly large value for the dose profile width would then be obtained. The developed film is then inspected under magnification to determine the dose profile width at the isocenter (correcting for geometric magnification). The measured dose profile widths should not significantly exceed the corresponding measured image slice thicknesses.

At acceptance, this test may also be performed on single and multi-slice “helical” (or “spiral”) CT systems with the assistance of a CT engineer. “Ready-Pack” film is wrapped around a lead-lined, cylindrical object whose circumference is slightly smaller than the length of the film. The CT engineer removes the scanner covers allowing access to the pre-patient collimation. A strip of lead tape is used to block all but 1 cm of the fan beam, the opening being centered on the central ray. The phantom is placed at the scanner’s isocenter and exposed using a variety of pitch settings.

The resulting patterns on the film allow for evaluation of table index relative to gantry rotation (actual pitch) as well as dose profile under dynamic conditions. Care should be taken to allow for magnification effects due to the finite radius of the cylinder. This test need only be performed at acceptance.

12.2.3 Slice Positioning Accuracy

QC comprises several tests that should be performed monthly to semiannually. These tests are for (1) accuracy of the slice localization light(s), (2) accuracy of slice positioning using prescriptions from the digital survey radiograph, and (3) accuracy of the table motion with slice incrementation. In testing the accuracy of the slice localization lights, it is important to note the accuracy of each light that is used. In testing the accuracy of the table motion, results should include the effects of reversal of the table motion.

12.2.4 CT Number Scale Accuracy and Stability

This test should be performed monthly to semiannually. A phantom containing a variety of materials with a wide range of CT numbers is scanned in axial mode using a set technique. The CT numbers of the materials are measured in the image and compared with standard values from the manufacturer and with previously measured values. Some typical materials used are polyethylene, water, PMMA, polycarbonate, nylon, polystyrene, and Teflon^{TM}. The measured values should remain relatively constant for a particular CT scanner. Large changes indicate malfunctions or calibration problems. The values obtained for identical materials can differ substantially for different CT scanners, due to differences in kV, filtration, detector absorption, and beam hardening corrections. When the CT number thus obtained is plotted against linear attenuation coefficient, a straight line should result with a correlation coefficient very close to 1.00, although the slope of this line will be equal to the CT constant used (typically 1000) divided by the linear attenuation coefficient for water at the effective beam energy in use. For a scanner that uses a CT constant of 1000 that is operated at 120 kVp with a hardened beam, the slope of the regression line should be 5200. Although this value will differ between scanners, it should remain constant (within ±5%) for a given system over time.

12.2.5 Spatial Resolution (Image Sharpness)

This test should be performed monthly to semiannually. In the axial mode, this test is most commonly performed by imaging phantoms containing suitable resolution objects in the x-y plane. These objects may be a series of rods of varying sizes that will image as dots, or a series of plates of varying sizes that will image as lines. Because there is more to visualize, the plate phantoms may sometimes indicate better resolution than rod phantoms. In call cases, the phantoms should

be of high-contrast constructions with differences of typically 1000 HU between the rods or plates and surrounding material. The use of significantly lower contrast phantoms (e.g., 100 HU) is not recommended, though they could be used to give measurements related to the modulation transfer function (MTF). Older resolution phantoms whose smallest object sizes are greater than 0.5 mm are not suitable for resolution on present day CT scanners. Some CT scanners are capable of calculating resolution limits, MTFs, or point spread functions automatically by scanning a phantom containing a resolution phantom or thin wire. These results may be useful in providing alternative information regarding image sharpness. The thin-wire phantoms are sensitive to proper alignment along the z-axis. For helical CT the wire must have z-axis extension of at least the slice thickness plus twice the table feed per tube revolution.[48] Measurements from a periodic rod or bar pattern may be more reproducible in clinical situations.

The in-plane spatial resolution should be evaluated in the axial mode using both standard and high-resolution algorithms with a single slice thickness. Particularly with high-resolution algorithms, the pixel size in the standard scan field of view may limit the observed resolution, which may also be affected by the orientation and placement of the resolution pattern. In this case a smaller scan field of view may need to be imaged to demonstrate the true resolution capability of the CT scanner.

The in-plane spatial resolution in a helical scan at isocenter should be relatively independent of pitch and equivalent to that obtained from a conventional (axial) scan when all scan parameters are identical.[58] However, if an appropriate phantom is available, the in-plane resolution for helical scans should be measured to verify equivalence. For reproducible results, the medical physicist should carefully evaluate any phantom used and select a pitch which limits the z-axis extension of the scan to avoid introducing artifacts.

In clinical situations, both the in-plane and longitudinal resolution contribute to overall image sharpness and detail in helical scans. Unfortunately, there are few, if any, commercial phantoms available to test longitudinal resolution for helical CT. A plastic "hole" phantom described by Polacin[59] has been used with some success.[60] Reconstruction software must be available to prepare multiplanar reformations (MPR) of the test object. If the appropriate software and a phantom are available, longitudinal resolution should be evaluated and monitored for several combinations of collimation and pitch. Reconstruction intervals should be chosen to be no more than 0.2 times the collimation.[61]

12.2.6 Low-Contrast Detectability

This test should be performed quarterly to annually. It is important to perform this test in a way that minimizes the variations due to its subjectivity. Low-contrast detectability phantoms should contain objects of less than 1% (10 HU)

contrast, due to the improved imaging capabilities of modern CT scanners. The test phantom may contain objects of varying size and/or contrast.[62] The phantom should first be scanned using typical clinical techniques, then using techniques higher and lower than those in clinical use. In the images, the smallest size objects that are perceivable at each contrast and technique level should be recorded. Visibility of large objects should improve with increasing technique. Small object visibility will also improve, but will ultimately be constrained by spatial resolution limitations.

To minimize errors due to the stochastic nature of the image, for each size and contrast several objects should be available for viewing. Because of the inherent subjectivity of this test, the performance of a particular scanner over time can probably be more precisely monitored using the image noise numbers.

Because of the lack of commercial phantoms and general inexperience with three-dimensional (3-D) low-contrast measurements, helical low-contrast detectability in the longitudinal direction remains an issue to be resolved in the future.

12.2.7 Dosimetry of Axial Scans

These tests should be performed quarterly to annually. The method described by the FDA for dose evaluation is a measurement of the CTDI (CT Dose Index). We will refer to this measurement as the $CTDI_{FDA}$. This measurement requires the use of specified CTDI phantoms composed of PMMA with diameters of 16 cm and 32 cm and a cylindrical ion chamber with an active length of 14 cm. Exposure measurements are made by placing the chamber in holes near the surface of the phantoms and also at their centers. These measurements also require the use of lead filters to shorten the active length of the chamber when measuring slices thinner than 10 mm, since the exposure is only measured over a length of 14 times the nominal slice thickness. As a result, these measurements are cumbersome and time-consuming. Also the measurement results for slice thicknesses of 5 cm and below can quite misleading, since in such cases much of the single slice dose profile is excluded from the measurement.

A much better CT Dose Index has been defined in a new standard from the IEC (International Electrotechnical Commission). In this measurement the exposure is measured over a 100 mm length for all slice thicknesses. As with the $CTDI_{FDA}$, this IEC measurement standard is performed with the ion chamber in holes near the surface and at the center of the phantoms and is then referred to as the $CTDI_{100}$. A weighted CTDI is also part of this standard and is obtained by adding together two-thirds of the surface $CTDI_{100}$ with one-third of the central $CTDI_{100}$. With this method, the requirement for the lead filters is eliminated and only a 10 cm chamber and phantoms are needed. Also, nearly all the single slice dose profile is detected in the measurement for all slice thicknesses. The $CTDI_{100}$ is very closely

related to the MSAD (Multiple Slice Average Dose) for all measured slice thicknesses. Manufacturers supply information on both $CTDI_{FDA}$ and $CTDI_{100}$ measurements for their scanners as a function of kVp, mAs, and slice thickness for surface and central ion chamber positions in both the 16 cm and 32 cm diameter phantoms. The results obtained by testing of a particular scanner should correspond to the values provided by the manufacturer.

There are many pitfalls in the measurement of CT dose about which the reader should be warned. A specific flaw in the definition of $CTDI_{FDA}$ is the lack of a specified means of converting the exposure measurement into a dose figure. At CT energies the conversion factor (f_{med}) to convert exposure (R) to dose in soft tissue (rad) is approximately 0.94. However, most manufacturers use the f_{med} for PMMA of about 0.78 to calculate CTDI, and one must be aware of this usage. If the $CTDI_{FDA}$ is used in an attempt to calculate the dose to the patient (or to the embryo or fetus) the dose may be underestimated due to the lower f_{med} used and also due to the exclusion of significant parts of the single slice dose profile for thinner slices, as discussed above. The use of the $CTDI_{100}$, instead, mostly corrects these two problems. In the definition of $CTDI_{100}$ the f_{med} is explicitly given as that for air: 0.87.

The measurement of surface dose by using a shorter cylindrical ion chamber on an imaging phantom will result in a substantial underestimate of the surface MSAD. Different CT scanners should not be compared by looking at only the central or surface CTDI or MSAD of a particular size phantom. Because of differences in pre-patient filters, different CT scanners have significant differences in the ratio of center to surface CTDI or MSAD.

A robust method for routine measurement of the radiation dose from helical scans has not yet been described. However, the dosimetry for a helical scan at 1:1 pitch and 10 mm collimation is not appreciably different from that obtained with contiguous 10 mm axial slices.[63] At this time, it is sufficient to verify performance using measurements of the $CTDI_{100}$ in axial modes only.

12.2.8 Dosimetry of the Digital Survey Radiograph

This test should be performed semiannually to annually. If only one dosimeter position is measured, it should be at the surface of the phantom nearest the x-ray source.

12.2.9 Resolution, Gray Scale, Image Distortion, and Artifacts in the Video Monitor and the Hard Copy

Distortion generally manifests as a variation of the vertical to horizontal scale. Monitor artifacts include burn spots, flicker, and prominence of horizontal scan lines. Hard copy artifacts also include processor problems (see section 16, **Hard Copy and Soft Copy Display Device Quality Control**).

12.3 Multislice CT Considerations

The rapid acceptance of multi-row CT scanners has presented new challenges for the physicists responsible for conducting acceptance tests. Several tests need to be addressed differently for these scanners, and others need considerable modification. A brief summary of the differences presented by multi-row detector CT systems is provided below.

12.3.1 Visual Inspection

The appearance of a water bath image obtained by all four (or more) channels of a multi-row CT system should be undertaken by visual inspection. Visual examination of all (4+) individual images collected in a single revolution should be conducted. Look for cupping, rings, and any recognizable noise pattern as you would with single-slice CT. This should be repeated for all slice thickness options, axial and helical modes, several pitches, and all reconstruction filter options. Although this may seem like a lot of effort, these images can be quickly examined by an experienced medical physicist. Noise measurements can also be obtained from these images. Noise is not necessarily independent of pitch in multi-slice CT depending algorithm used for reconstruction.[50,52,54] Be certain to evaluate noise and dependence on pitch for each particular scanner/vendor.

12.3.2 Radiation Beam Profile

Check the radiation beam profile at the center of gantry bore for all possible collimation options with the scanner set to operate in the single-slice mode. Be careful to avoid film overexposure and "bloom" of the beam appearance on the film. Expect these profiles to be slightly wider than the nominal collimation and wider than those found for axial and single-slice helical CT.[52] This is due to the requirement to exclude the penumbra from the outer detector rows.

12.3.3 Z-Axis Characteristics

Because most routine clinical exams utilize helical scan mode, the z-axis characteristics (SSP) are important to document during the acceptance procedure and then to monitor annually. Several approaches have been documented and are in the published literature.[48,49] The Slice Sensitivity Profile (SSP) is relatively easy to measure using a bead phantom although, for collimation less than 4 mm, some errors can be introduced depending on the size of the bead.[49] If an appropriate bead phantom is available, the phantom is scanned and images are reconstructed at intervals equal to one-tenth of the collimation. The maximum CT number obtained from a ROI tightly centered around the bead is plotted as a function of table position. After subtracting the background, one can calculate the FWHM, the full width at tenth maximum (FWTM), and/or the full width at tenth area (FWTA).

The SSP should be obtained and plotted for at least the commonly used collimation settings and pitches as single-slice systems and some multi-slice systems have (nearly) continuously variable pitch selections. Single-slice systems generally have a smooth degradation of SSP with increasing pitch.[58,59,61] On the other hand multi-slice systems have SSPs that are independent of pitch[54] or not predictably degraded.[50,60,64,65] For multi-slice systems that have specific combinations of collimation, pitch, and detector configuration, every effort should be made to characterize the SSP at each selectable combination at acceptance. For regular QC, spot checks of several of the combinations may be adequate to track performance. The shape of the SSP obtained with a bead phantom and reconstructed at one-tenth of the collimation should be inspected to ensure that it is a smooth curve and that the FWHM (or FWTM) meet manufacturer's specification.

12.3.4 Radiation Dose

Radiation dose may be higher with multi-slice CT than with similarly engineered single-slice CT due to the slightly larger radiation profiles required to exclude beam penumbra from the outer detectors. Some multi-slice systems also have a shorter SID. Be sure to check that your facility uses a dramatically reduced technique for pediatric CT exams.

12.4 After Tube Replacement

Check the following according to the indicated section:

- Evaluate phantom images for artifacts (to detect tube misalignment): section 12.1.
- Slice thickness and laser alignment: section 12.2.
- CT number calibration (for kV calibration): section 12.2.4.
- Spatial resolution to verify absence of geometric blurring: section 12.2.5.
- Patient dose (for mA calibration and to satisfy JCAHO): section 12.2.7.

13 QUALITY CONTROL FOR DARKROOMS, PROCESSORS, FILM, AND CASSETTES

Studies continue to show that film processing is a major problem area in diagnostic facilities.[66]

13.1 Daily

Sensitometry. We will limit our discussion to automatic processors only. Manual processing should not be used in diagnostic radiology. If workload is below 25 to 50 (14×17 in.) films per day, flooded replenishment is required.[67]

Sensitometry is performed to evaluate the day-to-day stability of the processor as well as to perform comparisons between processors, chemistries, and emulsions. Specific guidelines for setting up a sensitometry program for processors can be found in Gray et al. (1983).[68]

Sensitometry should be performed using the same emulsion type that is currently in clinical use in the processor. A 30-day supply of film for each processor in the department, all with the same emulsion batch number (or lot number) must be set aside and identified to be used for sensitometry only. The latent image is subject to fading after exposure. The degree of fading depends on a variety of variables. Fading is minimized by keeping the time between exposure and processing of the sensitometric strips as short as possible. The length of the time interval that is used is not as important as its consistency. To assure continuity when changing boxes of QC film (with differing lot numbers) a crossover should be performed.

13.2 Weekly

13.2.1 Darkroom Cleanliness

Dirt, dust, lint, and debris that are allowed to build up on surfaces in the darkroom are a potential source of image artifacts. The darkroom should be cleaned weekly (or more often as needed) and evaluated for cleanliness monthly. Cleaning consists of wiping all surfaces (including the feed tray, counter top, shelves, and floor) with a damp cloth or wet mop. Evaluation is conveniently performed using a hand-held, battery-powered UV-B lamp to inspect surfaces for dust and lint.

13.2.2 Cassettes

Cassettes should be periodically cleaned and inspected according to the manufacturer's recommendation. The intensifying screen and cassette exterior (non-tube side panel) should be marked with a unique identification number to facilitate all cassette QC activities.

Cassette cleaning. The intensifying screens of cassettes should be cleaned using screen cleaning solutions, materials, and procedures recommended by the manufacturer.[68] If the recommended solution is not available, mild soap and water may be substituted. In addition, the interior (other than the intensifying screen) and exterior of the cassettes should be cleaned. A hand-held UV inspection lamp with a type BL-B bulb may be used to aid in the evaluation of the effectiveness of the cleaning procedure.

Cassette Inspection and Evaluation. After cleaning, cassettes should be inspected for obvious deficiencies such as broken latches, chipped or stained intensifying screens, broken identification windows, etc. Cassettes should also be evaluated for screen-film contact, light leaks, and uniformity of exposure.[68]

13.3 Monthly

13.3.1 Film Storage

The location in which film is stored should be monitored monthly using a thermometer and hygrometer to assure that the film stock is being properly rotated and that temperature and humidity requirements are being met. The film manufacturer's requirements for storage conditions should be followed. In general, film (unexposed and unprocessed radiographs) should be stored in the 15° to 21°C range. Relative humidity should be in the 40% to 60% range. Unexposed film should be rotated and used before the film expiration date. Photographic chemicals should also be purchased in amounts that will ensure rapid turnover.

13.3.2 Darkroom Conditions

Darkroom temperature and humidity. Temperature and humidity in the darkroom should be checked monthly using a thermometer and hygrometer. Temperature should allow for a comfortable working environment (65° to 75°F). Low humidity may result in static artifacts while high humidity may cause film handling or transport problems. Humidity should be maintained between 40% and 60%.

Film fog (every 6 months). Darkroom fog levels should be measured using the facility's clinical films, primarily because medical x-ray films differ in their light sensitivity; therefore the film tested should have the same light sensitivity as the film used clinically. Using the facility's own film ensures this. There are several methods for measuring fog.[68–70] The main requirement in measuring fog is to preexpose the film in a cassette so that the latent image will result in a film density in the mid-density region of the film's characteristic curve. Film is most sensitive to ambient light at these densities. The film is then unloaded in the darkroom, positioned in a typical work area, partially covered with opaque paper, which shields half of the film from the darkroom ambient light. The film and paper are left out in the ambient light for 2 min. The film is then developed normally. If a visible border is observed corresponding to the bisected section of the film, then darkroom fog is present. If the density difference between the exposed and unexposed areas exceeds 0.05 OD, steps to reduce this level should be taken.

Darkroom fog may be attributable to light leaks or poor safelight conditions. To evaluate for light leaks, you should dark adapt your eyes for 10 to 15 min in the darkroom with all safelights turned off. The human eye is extremely sensitive to light when dark-adapted. Any visible light leaks should be eliminated.

Safelights should be those specified by the film manufacturer. The incandescent bulb should be frosted and its wattage should be according to the film manufacturer's specifications. Distance requirements (usually 4 ft or greater) should be adhered to, unless the light is an indirect safelight (the safe light is directed toward the ceiling). Too many safelights will also result in excessive fog, so attention

should be paid to all sources. Darkroom walls should be painted white to minimize the risk of personal injury while working in this dark environment.

Darkroom fog should be tested at least once every 6 months, or after any major change in film type used by the facility or after changes in safe light filters or light bulbs.

14 QUALITY CONTROL OF PHOTOSTIMULABLE PHOSPHOR SYSTEMS

The Diagnostic X-Ray Imaging Committee of the AAPM has established a task group (TG-10) to make recommendations on quality control of computed radiography (CR) systems. At the time of this writing, those recommendations are not available. The information in this section should be considered interim guidelines to be used only until the CR task group publishes its findings.

Most CR systems installed today are based either upon the photostimulable phosphor (PSP) technology introduced in the late 1970s (commonly referred to as computed radiography, or CR, systems) or on digital fluorography commonly found in many angiographic suites and, more recently, in fluoroscopic rooms as well. Digital angiography systems are covered in section 10 of this document. Detailed information on test procedures is system specific, requiring knowledge of the particular system being tested. Procedures and results for the Fuji AC-1 CR reader (and generally all the CR systems manufactured by Fuji) are available in the literature.[71] A rapid proliferation of CR systems is occurring at the time of this document publication. As such, system specific procedures are not outlined herein, rather the general tasks and procedures necessary to verify acceptable performance standards established at the initial acceptance testing. It is important to be aware of the operating procedures, specific capabilities and system indicators of each CR manufacturer and system before embarking upon acceptance testing or routine QC. Of note are the functions indicating the incident exposure on the plate and the methods of determining or selecting film density on the printed film. Daily, weekly, and monthly QC tests are typically performed by the radiologic technologists assigned to QC procedures in the department, or by the technologists most familiar with computed radiography. Semiannual, and particularly annual, tests are oriented for the medical physicist to verify system performance for an in-depth review and re-establishment of baseline performance levels as well as action limits.

14.1 Daily

The daily QC program for a CR system is based primarily on verification of processor sensitometry and general system condition. These tests are commonly performed by the technologist(s) assigned to quality control verification of systems

in radiology. The imaging plates may be cleaned according to manufacturer's recommendations if necessary, but this is usually not required. Dust and debris tend to build up in and around the insertion slot and may eventually get into the readout chamber. For this reason, it is recommended to carefully clean this area daily with a damp cloth. Canned air may be useful to blow dust out of hard to reach areas. Compressed air contains small amounts of oil and should not be used. The test frequency for any of the tasks listed below may be changed to longer intervals once a track record is established and verified. In some cases, particularly with troublesome or aging systems, it might be required to increase the frequency to more than daily. It is strongly recommended to maintain a log for each system in order to have a record of daily QC tasks and for trending analysis of the various tests undertaken.[2]

14.1.1 Visual Inspection

Wipe any dust, lint, or powder out of the insertion slot. Use canned (**not compressed**) air if necessary. Visually inspect power cables and connections for tightness, frayed cabling, discoloration, etc.

14.1.2 Processor Fluid Levels

Visually confirm proper level of fluids in developer, fixer, and wash tanks.

14.1.3 System Sensitometry

Run a laser-generated calibration strip and set the calibration values according to the manufacturer's instructions.

14.1.4 Processor Sensitometry

Run a sensitometry strip as you would for any processor to check the processor independently of the laser system. Unfortunately, some of the stand-alone systems were not designed for separate determination of processor status, making an independent measurement of the processor performance difficult. In order to perform the daily processor sensitometry, it may be necessary to darken the room, requiring its location to be in a darkroom environment.

14.1.5 Imaging Plate (IP) and Cassette Cleaning

Visually inspect the imaging plates and cassette assemblies for cleanliness. Clean as necessary per manufacturers instructions (**do not use standard screen cleaning solution on inspection plates** (**IPs**) **as it could damage the protective surface of the screen**). After cleaning, erase the plates in the CR reader prior to clinical use.

14.1.6 Film Supply

Check for low film supply from the control console using the software provided by the manufacturer.

14.1.7 IP Status Check

Erase any IPs whose status is uncertain.

14.2 Weekly

Weekly QC consists mostly of a thorough cleaning of both the system and the plates. As with daily tests, the frequency should be tailored to the expected change of system parameters and to the previous track record of logged events.

14.2.1 Filters and Vents

Clean all air filters and vents on both the CR system and the processor. In particularly dusty environments, this may need to be more frequent.

14.2.2 Primary Erasure

Perform a primary erasure of all plates. Be sure to account for the logic of stacker mechanism.

14.2.3 Plate Cleaning

All IPs should be cleaned according to manufacturer's recommendations only. After a couple of weeks of cleaning, determine whether less frequent cleaning is justified by noting the condition of the plates for dust, scratches, etc. in the log.

14.2.4 Light Leak Check

Check for light leaks, particularly at the junction between the CR unit and the processor.

14.3 Monthly

14.3.1 Processor

Clean and do preventive maintenance (PM) on processor. See section 12, **Quality Control of Computed Tomography Systems.**

14.3.2 Imaging Plate (IP)

Clean according to manufacturer's recommendations as necessary.

14.3.3 QC Log

Review the QC logs for short-term trends, specifically with variation from normal operating baseline data results.

14.3.4 Repeat Image Trends

Analyze repeat image trends. Document and determine any system malfunctions, image retakes, etc.

14.4 Semiannually

Every 6 months the imaging plate reader system should be evaluated for linearity of response and presence of artifacts that are machine based. The frequency of the linearity tests may be changed to yearly based upon a proven track record.

14.4.1 Linearity and Sensitivity

Check the response of selected IPs to several levels of radiation exposure. In this test, verification of proper optical density independent of the incident exposure should be accomplished. At the same time the manufacturer's method of establishing an estimate of the incident exposure on the plate can be verified when measuring the incident exposure independently with a calibrated radiation detector (see section 14.5.3).

14.4.2 Image Quality

Evaluate a selected group of IPs for artifacts. This is accomplished by uniformly exposing a cassette to a nominal radiation exposure (e.g., 1 mR) and evaluating the resultant film image with a standardized image acquisition and processing routine. Review the QC log for long-term (e.g., monthly) trends that require adjustment.

14.5 At Acceptance and Annually Thereafter

Every year the system should have a complete periodic maintenance inspection by a qualified engineer (vendor or specially trained engineer). Following this, the medical physicist should repeat the tests performed at acceptance and determine the degree of degradation, if any.

14.5.1 System Inventory and Visual Inspection

Record all pertinent serial numbers and check against original inventory.

14.5.2 IP Dark Noise

Perform a primary erasure on all IPs. Process several (e.g., one small, one medium, and one large) unexposed IP using a high-contrast processing film print mode for the particular CR reader. Determine the incident exposure estimate based upon the "sensitivity number" or "exposure index" or other specific exposure indicator. No incident exposure should be recorded on the resultant image. Check for any image artifacts on the resultant hard-copy images. If soft-copy image display is available, use a window width and window level adjustment (narrow window width and small window level settings) to maximize the sensitivity of the displayed image to any possible artifacts (e.g., fixed point noise, image shading).

14.5.3 System Linearity and Sensitivity

Uniformly expose several plates of each dimension to 0.1, 1.0, and 10 mR (you must measure the incident exposure with a calibrated ionization chamber) using a "standard" kV (e.g., 80 kVp), added filtration (e.g., 1 mm Cu), field coverage (e.g., 80% of the active area of the plate), and geometry (e.g., extended SID such as 180 cm) to minimize image non-uniformities potentially caused by heel effect, etc. Using a "standard" readout and processing algorithm developed for exposure tests, (e.g., for the Fuji system a semi-automatic readout method is preferred) the resultant film images should have a constant image density across the field of view, and be within 0.2 OD (definitely within 0.5 OD) of the target OD. Measured exposures compared to the exposures determined by the CR system should agree to within ±20% over the 3 orders of magnitude incident exposure. Action should be taken for substandard performance levels beyond established limits.

14.5.4 Plate-to-plate Uniformity and Reproducibility

Compare the ODs from similar images acquired in 14.5.3 for uniformity of response and reproducibility. All film images should have an image uniformity to within ±0.25 OD of the central density as determined with a calibrated transmission densitometer.

14.5.5 Image Geometric Uniformity and Distance Measurements

Test objects (e.g., thin, partial attenuation objects such as a circular aluminum or copper filters, and/or lead-bar resolution test patterns) are imaged on different areas of the IP (e.g., four quadrants) with minimum magnification (contact imaging), using a standard acquisition protocol and reasonable incident exposure (e.g., 1 mR). Verification of pixel calibration and pixel dimensions along the rows ("x" dimension) and columns ("y" dimension) is performed for each quadrant, and results should be within 5% of each other. Hard-copy images should be evaluated for distance accuracy, taking into consideration the reduction factor that is often

applied to the CR images. Each available combination of IP size and reduction factor (e.g., 1 on 1 versus 2 on 1 image format) should be tested. The image reduction factor accuracy indicator should be within ±5% of the true (measured) value.

14.5.6 Spatial Resolution

Obtain low kV images at a moderate incident exposure (e.g., 50 kVp and 5 mAs at 180 cm with no filtration) of a resolution pattern (capable of 1 to 5 c/mm) in contact with the cassette for each IP format and plate size. This test can be accomplished simultaneously with the tests in 14.5.5. Both horizontal (row) and vertical (column) resolution should be tested. (Note: Slightly angle the bar phantom by a couple of degrees to the horizontal and vertical to minimize moire and line-pairing patterns that can interfere with the measurements; do not, however use a large angle such as 45 degrees, as this will likely underestimate the resolution capabilities of the detector.) Use of multiple patterns centrally and peripherally located on the cassette allows simultaneous measurement of central and peripheral resolution. Process the IPs with a high-contrast algorithm, and determine the limiting resolution in the horizontal and vertical directions on the hard copy and the soft-copy image (if available). All clinically used combinations of reduction factor and format should be tested. The measured resolution should be within 10% of the theoretical resolution based upon the sampling frequency of the imaging plate as specified by the manufacturer.

14.5.7 Laser Evaluation

In addition to the tests in section 14.5.6, perform the following: Obtain an image of an opaque straight-edge positioned over the center of the largest and smallest cassettes available on the reader. Ensure that the straight-edge is perpendicular to the laser scan lines (Note: The laser scan lines are typically perpendicular to the long dimension of the imaging plate, e.g., the 17 in. dimension of the 14×17 in. plate). Process the IP using a high-contrast algorithm and the highest sampling rate available (minimum demagnification). Check for laser jitter and banding, particularly at the edges of the bright-dark interface.

14.5.8 Low Contrast Resolution

Obtain several contact images of a Leed[35] or UAB[34] low-contrast phantom at the “calibrated” kV for the phantom for each IP format and image size.

The mAs should be set to deliver incident exposures of approximately 1 mR, or as used at acceptance. Process using a high-contrast algorithm as well as an edge enhancement algorithm. Evaluate the images for detectable contrast as a function of exposure, and compare to baseline measurements. Since this test is dependent on the type of phantom and the subjectivity of the person doing the evaluation, a standardized evaluation routine should be developed for several measurements over an initial period.

14.5.9 User-Controlled Density and Contrast Commands

Obtain several images of an appropriate step wedge (e.g., calibrated aluminum step wedge for characteristic curve measurements of screen-film combinations) on a number of IPs using a fixed radiographic technique. A variety of contrast and speed settings typically used in the clinical setting should be tested to determine and verify the appropriateness of the resulting density and contrast changes.

14.5.10 Miscellaneous CR Issues

Evaluation of the system log for trend analysis over the period of a year on a month-by-month basis for each of the various tested parameters is essential. Artifact identification (both system and non-system sources) and causes should be logged and reviewed on a yearly basis. Preventive maintenance and unscheduled maintenance logs should be reviewed at the yearly testing. Feedback from the radiologists regarding image presentation, processing algorithms, and radiographic techniques should be analyzed. Exposure incident on the plates should be tracked to analyze the trends of the radiologic technologists in providing the optimal exposures (around a 200 speed equivalent screen-film combination) for a majority of the computed radiographs, particularly since the system compensates for under- and overexposures with respect to output image optical density.

15 VIEW BOX QC

Quite often radiographic light view boxes are overlooked in quality assurance programs. The perception of image quality is reliant upon the brightness of the view box. As view box light sources age their brightness diminishes. This gradually affects the perceived density and contrast of the radiographic image. Over a period of time, electrical wiring can become frayed and brittle. It is therefore recommended that radiographic view boxes periodically be evaluated for brightness balance, color balance, cleanliness, and electrical safety.

15.1 Weekly

Clean the front of the diffuser panels of the light bank. The surface should be free of dust, debris, film marker artifacts, smudges, and fingerprints.

15.2. Annually or More Frequently If Indicated

15.2.1 Clean Diffuser Panel and View Box

Clean the back of the diffuser panel and the inside of the view box. The box and panel should be free from any dust and debris that may decrease the amount of reflected light.

15.2.2 Check Diffuser Panel

Check that each panel correctly senses the presence of a film and turns on appropriately (if so equipped).

15.2.3 Inspect Wiring

Inspect the electrical wiring for frayed wiring, loose connections, evidence of arcing in relays and switches, and potential short-circuited wiring.

15.2.4 Inspect View Box

Visually inspect the entire view box unit to assure that all bulbs are of the same color.

15.2.5 Measure Light Output

Measure the light output from each panel through the diffuser for minimum intensity and for brightness balance between adjacent panels and banks (all should be within ±20% of the target spec). The task group recommends the following minimum light outputs for radiographic view boxes:

General purpose: 2500 nits (cd/m^2).

Mammographic: Follow ACR recommendations (currently 3000 nits).

15.3 Annually

Test for electrical leakage by a qualified electrician.

16 HARD-COPY AND SOFT-COPY DISPLAY DEVICE QUALITY CONTROL

Hard-copy devices are used in one of two ways: with and without operator adjustment of window and level (W/L) settings. The QC procedures for hard-copy devices will vary depending upon which of these operations is used.

For example, many CT departments utilize pre-programmed W/L settings for hard-copy production. This is possible because the CT number associated with a particular type of tissue varies insignificantly assuming correct CT calibration and the use of fixed kV. Under these conditions, the appearance of the CT image on the control console monitor has no bearing on the contrast and density of the final hard-copy image. The operator makes no adjustments to the image density or contrast. In this case, the QC program should guarantee that, for a given data set windowed and leveled in a prescribed manner, the contrast and brightness of the resulting image are constant from copy to copy, day in and day out. If multiple CT devices are in use, the same data set from any scanner, windowed and leveled in

the prescribed manner, should also result in the same hard-copy image density and contrast from scanner to scanner. This is an example of a device that is operated without operator adjustment.

Other modalities do not lend themselves to the use of prescribed window-level settings. For example, in MRI the signal strength associated with a glioma may not be reproducible from scan to scan even on the same patient. In order to properly record the pathology of interest, operator adjustment of W/L is essential. These adjustments are made by viewing the data set at a video monitor with the expectation that the resulting hard copy will match the image on the monitor. Therefore, it is essential that the contrast and brightness settings on the monitor be adjusted such that the contrast transfer function (CTF) of the monitor closely approximates that of the printer.

In addition, for a given data set windowed and leveled in a prescribed manner, the contrast and brightness of the resulting image must be constant from copy to copy, day in and day out. If multiple MR devices are in use, the same data set from any scanner, windowed and leveled in the prescribed manner, should also result in the same hard-copy image density and contrast from scanner to scanner.

16.1 Hard-Copy Device

The hard-copy system should be checked for constancy of the CTF in accordance with the frequency specified in section 1.3. The CTF of the camera will depend on the power of the exposing source (laser, thermal print head, or internal video display), the calibration look-up table (LUT) and the media response curve [H&D (Hirter & Driffield) for conventional film]. Most cameras have a calibration function available to the operator which is intended to perform this test. The operator selects the appropriate test pattern and prints it. The result is a density step wedge that can be measured to establish the CTF of the camera. Some cameras have two calibration step wedge generators, one which is essentially uncorrected (used to generate a new correction LUT, and one which is corrected (by a previously-generated calibration LUT) and may or may not be further modified by an additional modality LUT (a CT modality LUT may not produce the same CTF as a MRI modality LUT).

One may wish to check the CTF of the entire system (acquisition device, interface, source, LUTs, chemistry, film) by printing a standard test image from the operator's console. Many systems utilize a SMPTE test pattern for this purpose. It may be necessary to get instructions from a service engineer to display and print this image. Another method is to utilize the "gray bar" that is printed with each image on most systems. This may be an option which can be switched on and off by the operator or service engineer. Utilization of the gray bar effectively allows a CTF pattern to be printed with every image. This may be an invaluable tool in determining the cause of image quality problems and is therefore highly recommended.

A uniformly gray image should also be generated daily and inspected for artifacts such as washboard patterns and lines.

16.2 Display Monitor

Matching between the monitor and the hard copy is very difficult to establish, as it will depend on factors such as the ambient light level at the console and the response of the operator's visual system, which will vary between individuals. It is best to perform the initial set-up of the display with several operators present so that all can agree on the matching between hard copy and display. A responsible physician who reads the exams should first designate an acceptable hard-copy image. The illumination in the control room should be darkened to a level that permits a safe work environment without compromising the visibility of low-contrast details in the monitor display. Brightness and contrast settings on the monitor should then be adjusted to match (as closely as possible) the hard copy. When all agree that the monitor accurately reflects the contrast seen in the image, the monitor is declared calibrated.

At this point, the illumination of the control console (with the monitor off, or blank) should be measured with a calibrated photometer and recorded. A properly windowed and leveled test pattern image should then be displayed at five pixel values (Peak white, 70%–80% of maximum, 50% of maximum, 20%–30% of maximum, and black, or 0% pixel value) and measured with a calibrated photometer. This operation should be repeated on a quarterly basis and after any change to monitor brightness and contrast settings to maintain constancy.

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