Canadian Association of Provincial Cancer Agencies

Standards for Quality Control at Canadian Radiation Treatment Centres

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Electronic Portal Imaging Devices

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Developed, revised and approved by THE CANADIAN ORGANIZATION OF MEDICAL PHYSICS and THE CANADIAN COLLEGE OF PHYSICISTS IN MEDICINE

Source document: **Rasika Rajapakshe (Kelowna)**

External Reviewer: **Stephen Pistorius (Winnipeg)**

Primary Task Group Reviewer: **Peter Dunscombe (Calgary)**

Secondary Task Group Reviewer: **George Mawko (Halifax)**

Task Group Members: Clement Arsenault, Jean-Pierre Bissonnette, Peter Dunscombe (Chair), Harry Johnson, George Mawko, Jan Seuntjens

Document development and review process: The quality control documents in this series originated from one of two sources. Some of the source documents were commissioned by CAPCA specifically for the purpose of developing national standards. This is one such document. Others had been previously developed for provincial use by the Physics Professional Affairs Committee of Cancer Care Ontario (formerly the Ontario Cancer Treatment and Research Foundation). The source documents were developed over an extended period of time from 1989 to the present. Each source document has been reviewed by one or more independent Canadian medical physicists and the reviews accepted by the task group as they became available. The primary and secondary task group reviewers then examined the source document, the external review(s) and any appropriate published literature to propose quality control standards, objectives and criteria to the full task group. The full task group met electronically and, by a consensus approach, developed the present document. The task group gratefully acknowledges the effort contributed by the author(s) of the source document and the reviewer(s) whose work forms the basis of this document. Review, updating and reformatting have been performed and for any errors or omissions introduced in this process the task group takes full responsibility.

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Acronyms, Synonyms and Definitions

AAPM	American Association of Physicists in Medicine
ADCL	Accredited Dosimetry Calibration Laboratory
Al	Aluminum
AMFPI	Active Matrix Flat Panel Imaging Devices
ANSI	American National Standards Institute
BSF	Back scatter factor
CAPCA	Canadian Association of Provincial Cancer Agencies
CCO	CancerCare Ontario
CCPM	Canadian College of Physicists in Medicine
CNSC	Canadian Nuclear Safety Commission (Successor to the Atomic Energy Control Board - AECB)
COMP	Canadian Organization of Medical Physics
CSA	Canadian Standards Association
CT	Computed Tomography
CTV	Clinical target volume
Cu	Copper
EPI(D)	Electronic Portal Imaging (Device)
FWHM	Full width at half maximum
Gleason score	A numerical system based on major and minor histological patterns
Gy	Gray, unit of absorbed dose (1J/kg)
HVL	Half value layer
IAEA	International Atomic Energy Agency
ICRU	International Commission on Radiation Units and Measurements
IEC	International Electrotechnical Commission (Geneva, Switzerland)
IMRT	Intensity modulated radiation therapy
INMS-NRCC	Institute for National Measurement Standards of the National Research Council of Canada
IPEM	Institution of Physics and Engineering in Medicine
IPSM	Institute of Physical Sciences in Medicine

ISO	International Organization for Standardization
Isocentre	The intersection of the axes of collimator and gantry rotation
Linac	Electron linear accelerator
MLC	Multileaf Collimator
mMLC	mini- or micro-Multileaf Collimator
MPPAC	Medical Physics Professional Advisory Committee
MRI	Magnetic Resonance Imaging
MU	Monitor unit
NCRP	National Council on Radiation Protection and Measurements
NIST	National Institute of Standards and Technology
NRCC	National Research Council of Canada
NTD	Normal treatment distance
ODI	Optical distance indicator
PMMA	Polymethyl methacrylate
PDD	Percentage depth dose
PSA	Prostate specific antigen
PTV	Planning target volume
QA	Quality assurance (the program)
QC	Quality Control (specific tasks)
SSD	Source-to-surface distance
SRS	Stereotactic radiosurgery
SRT	Stereotactic radiotherapy
STP	Standard temperature and pressure
TBI	Total body irradiation
TG-	Publications of various AAPM Quality Assurance Task Groups
TLD	Thermoluminescent dosimeter
U	air-kerma strength (μGy m^2/h)
WHO	World Health Organization
σ	Standard deviation
ε_T	Timer/(monitor) end error

Frequencies:

Daily:	Once during every treatment day and separated by at least 12 hours.
Weekly:	On average once every 7 days and at intervals of between 5 and 9 days
Monthly:	On average once every four weeks and at intervals of between 3 and 5 weeks
Annually	On average once every 12 months and at intervals of between 10 and 14 months.

Output:

Output constancy check: a daily instrument reading (corrected for temperature and pressure) taken under reproducible geometrical conditions designed to check that the radiation output (e.g. cGy/MU) values in clinical use are not grossly in error.

Output Measurement: a determination of the absorbed dose to water (cGy) at a reference point in the photon beam for a chosen field size and beam quality.

Introduction

Patients receiving treatment in a Canadian cancer centre have a reasonable expectation that the quality of their treatment is independent of their geographic location or the centre they are attending. Insofar as medical physicists contribute to treatment quality, this expectation will be more closely met through the harmonisation of quality control standards across the country. The Canadian Association of Provincial Cancer Agencies (CAPCA) has initiated the process of standardisation of treatment quality in Canada through its draft document "Standards for Quality Assurance at Canadian Radiation Treatment Centres". This present document is an appendix to the CAPCA document and is concerned with quality control standards for use with electronic portal imaging devices (EPIDs). The source document was originally commissioned by CAPCA.

A quality control program on equipment used to deliver radiotherapy in a Canadian cancer centre must be carried out by, or under the direct supervision of, a qualified medical physicist. Here, a qualified medical physicist is one who is certified in Radiation Oncology Physics by the Canadian College of Physicists in Medicine or who holds equivalent certification. This individual, known as the supervising physicist, is responsible for ensuring compliance with the local quality control protocol, maintaining appropriate documentation, taking appropriate remedial actions and communication with other members of the radiation therapy team concerning the operational state of the equipment. Depending on local circumstances and organisational structure, one physicist may supervise quality control on all equipment or the responsibilities may be dispersed. However, the supervising physicist for a particular piece of equipment must have a direct line of communication to the Quality Assurance Committee for the Radiation Treatment Program.

This document contains specific performance objectives and criteria that the equipment should meet in order to assure an acceptable level of treatment quality. However, it does not recommend how the tests should be carried out. It is the responsibility of the supervising physicist to ensure that the locally available test equipment and procedures are sufficiently sensitive to establish compliance or otherwise with the objectives and criteria specified here. There are many publications dealing with the performance, specifications and quality control of electronic portal imaging devices (Dong, 1994; Klein, 1996; Low, 1996; Rajapakshe, 1993; Rajapakshe, 1996; Shalev, 1998; AAPM, 2001). Most of these publications have extensive reference lists. Some have detailed descriptions of how to conduct the various quality control tests.

Radiation safety activities are beyond the scope of this report. However, such activities may be combined with routine quality control programs for equipment.

A successful quality assurance program is critically dependent upon adequately trained staff and a culture of continuous quality improvement. Educational opportunities to be offered to quality control staff must include new staff orientation, in-house continuing education, conference participation and manufacturer's courses as appropriate. All such

educational activities must be documented as part of the quality assurance program. Continuous quality improvement embodies the concepts of documentation, monitoring, review and feedback.

The standards promoted in this document are based on the experience of the author and reviewers and are broadly consistent with recommendations from other jurisdictions (AAPM, 2001; IPEM, 1999). Although this document has undergone extensive review it is possible that errors and inaccuracies remain. It is hoped that the users of these standards will contribute to their further development through the identification of shortcomings and advances in knowledge that could be incorporated in future versions.

Performance Objectives and Criteria

Objectives and criteria for the evaluation of the performance of radiotherapy equipment fall into several categories.

1. Functionality. Equipment systems and sub-systems for which the criterion of performance is "Functional" are either working correctly or not. Such systems are commonly associated with the safety features of the equipment or installation. Operating a facility which has failed a test of functionality has the potential to expose patients and staff to hazardous conditions.

2. Reproducibilty. The results of routine quality control tests, for which reproducibility is the criterion, are assessed against the results obtained at installation from the accepted unit. Tolerances and action levels may be set for parameters that can be quantified.

3. Accuracy. Accuracy is the deviation of the measured value of a parameter from its expected or defined value. Examples are isocentre diameter and reference dosimetry (cGy/MU).

4. Characterisation and documentation. In some cases it is necessary to make measurements to characterise the performance of a piece of equipment before it can be used clinically. An example is the measurement of the ion collection efficiency.

5. Completeness. The use of this term is restricted to the periodic review of quality control documentation.

For quantities that can be measured, tolerance and action levels may be defined.

i. Tolerance Level. For a performance parameter that can be measured, a tolerance level is defined. If the difference between the measured value and its expected or defined value is at or below the stated tolerance level then no further action is required as regards that performance parameter.

ii Action Level. If the difference between the measured value and its expected or defined value exceeds the action level then a response is required immediately. The ideal response is to bring the system back to a state of functioning which meets all tolerance levels. If this is not immediately possible, then the use of the equipment must be restricted to clinical situations in which the identified inadequate performance is of no or acceptable and understood clinical significance. The decision concerning the most appropriate response is made by the supervising physicist in conjunction with the users of the equipment and others as appropriate. If the difference between the measured value and its expected or defined value lies between the tolerance and action levels, several courses of action are open. For a problem that is easily and quickly rectifiable, remedial action should be taken at once. An alternative course of action is to delay remedial action

until the next scheduled maintenance period. Finally, the decision may be made to monitor the performance of the parameter in question over a period of time and to postpone a decision until the behaviour of the parameter is confirmed. Once again, this will be a decision made by the supervising physicist in consultation with the users of the equipment and others as appropriate.

Documentation of equipment performance is essential and is discussed later. However, at the conclusion of a series of quality control tests it is essential to inform the users of the equipment of its status. If performance is within tolerance, verbal communication with the users is sufficient. If one or more parameters fails to meet Action Level criteria, and immediate remedial action is not possible, then the users of the equipment must be informed in writing of the conditions under which the equipment may be used. Compliance with Action Levels but failure to meet Tolerance Levels for one or more parameters may be communicated verbally or in writing depending on the parameters and personnel involved. The judgement of those involved will be required to make this decision.

It is recognized that older equipment, which either was not designed to or is currently unable to meet the standards described here, is still providing a useful service to patients in many centres. In such cases, the equipment may fail to meet all action level requirements and the use of such equipment must be restricted to clinical situations in which the identified inadequate performance is of no or acceptable and understood clinical significance.

System Description

Portal imaging is the most widely available method today for evaluating and documenting the degree of geometric treatment accuracy in external beam radiotherapy. Radiographic film has been used in the past for this purpose. However, the difficulties associated with film imaging (Boyer, 1992) encouraged the development of Electronic Portal Imaging Devices in the late 1980's. Electronic Portal Imaging Devices (EPIDs) are digital imaging systems utilized to verify the geometric treatment accuracy in external beam radiation therapy.

Although commercial EPIDs have been available since the early 1990's, it is recognized that the wide spread clinical use of these systems is still to be realized. As a result, Task Group 58 of the AAPM has prepared a report to provide information to enhance and encourage effective use of these systems (AAPM, 2001).

In the past, the majority of patients undergoing radiation treatments required one or more treatment simulations before or during treatment on a conventional simulator. One aspect of this simulation process is the radiological documentation of the approved field portals. However, the recent widespread use of CT scanners combined with virtual simulation software has made this process somewhat redundant. Consequently, more and more centres are leaving out the conventional simulation process and are proceeding directly to treatment with an EPID as the primary verification mechanism. Electronic Portal Imaging Devices are therefore becoming important tools in radiation treatment facilities.

Although a variety of systems has been examined and developed for electronic portal imaging, only a few have been commercially realized: video-based (fluoroscopic) systems, liquid matrix ion chamber systems, and, most recently, Active Matrix Flat Panel Imaging (AMFPI) devices. Readers are referred to two comprehensive reviews (Boyer, 1992; Webb, 1993) for details of other systems. It is anticipated that, with the increasing proliferation of the AMFPI devices, especially now that major radiotherapy vendors are marketing their versions of this new technology, the other two types will gradually become obsolete.

Video-based systems:

The imaging system consists of a metal/phosphor screen that converts the transmission x-ray image to a light image, which is viewed by a video (vacuum tube or CCD) camera via single or double 45^{o} front-coated mirror(s). The video signal from the camera is then digitized by a frame grabber system. In most cases multiple video frames are averaged to obtain an image (Boyer, 1992). The major drawback in these systems is the very poor light collection efficiency between the phosphor screen and the video camera target, which is in the order of 10^{-4}.

Liquid Matrix Ion Chamber systems

The imaging system consists of a matrix of 256x256 liquid-filled ionization chambers located in a sensitive area of $32x32cm^2$ sandwiched between two printed circuit boards (PCB). The ionization of the liquid in the chambers resulting from the radiation is measured by applying a high voltage to the electrodes of each chamber. Each row of the ionization chamber matrix is scanned by switching on a high polarizing voltage on the 256 chambers of one row and by reading out the ionization current with 256 electrometers. A complete image is obtained by subsequently switching on the polarizing voltage at each row and digitizing the signal. Both the time that a high voltage is applied on each row and the number of readouts of the electrometer are determined by the image acquisition mode.

Active Matrix Flat Panel Imagers

Originally developed by a group at the University of Michigan (Antonuk, 1996), this system consists of a large two-dimensional array of photodiodes fabricated from amorphous silicon deposited on a glass substrate. Amorphous silicon exhibits extremely high resistance to radiation damage. Although the array itself is sensitive to radiation, commercial implementations generally place the array in direct contact with a copper plate/phosphor screen detector to enhance x ray detection. Pixel sizes range from 400 to 780 microns on a side. Amorphous silicon imagers can be thought of as being similar to video-based systems except for the direct optical coupling between the phosphor screen and the camera target, thus enabling a 10^4 improvement in the detection of optical photons compared to video systems. The challenge associated with these imagers is the gradual radiation damage of the nearby electronics. Little data is available for the expected lifetime of these devices as the clinical introduction of these devices is recent at the time of this writing.

Acceptance Testing and Commissioning

Electronic portal imaging devices that are newly acquired or substantially upgraded require acceptance testing before being put into clinical service. Acceptance tests have three purposes:

- to ensure that the unit meets stated specifications,
- to establish baseline parameters for the future quality control program,
- to familiarize the customer with operation of the unit.

Acceptance tests are customarily described in a document prepared by the vendor, although the purchaser may wish to specify additional tests. The document is signed by the purchaser upon satisfactory completion of testing, before which formal purchase of the unit should not be completed.

The standards for electronic portal imaging device acceptance testing should be consistent with routine quality control objectives and criteria. In particular, there is no reason why a new or upgraded EPID, and its associated safety systems, should not meet the Tolerance Levels detailed later in this document (Table 1). Imaging, mechanical, and safety tests must be included. The tests should be performed by, or under the supervision of, a qualified medical physicist.

Adherence to these standards, Table 1, must be demonstrated and documented, in or outside of the vendor's acceptance testing protocol, before a new EPID or major upgrade is accepted, and put into clinical service. Also, an appropriate subset of acceptance tests must be performed after any repair or preventive maintenance interventions on the EPID. The extent of testing required must be judged by a qualified medical physicist.

Commissioning generally refers to the acquisition of additional measured data from a unit after most acceptance testing is completed, with two purposes:

- for subsequent calculations, for example, involving radiation dose,
- to establish baseline parameters for the future quality control program.

For EPIDs, the latter purpose dominates commissioning. Clearly all the tests listed in Table 1 must be performed at this time with the intended local test equipment and protocols if meaningful baselines are to be established.

Quality Control of Equipment

The purpose of a quality control program is to assure that operational standards for a system that were considered acceptable at the time of purchase continue to be maintained, as closely as possible, over the life of the unit. Thus, quality control tests typically are periodic repetitions, partial or full, of acceptance and commissioning tests. For EPIDs, tests are required for mechanical, imaging, computer workstation, software/clinical tools and for safety systems. However, given the variability of EPID designs, it is challenging to identify a core set of quality control procedures for all systems. The level of detail that can be reasonably specified is also somewhat limited.

The standards for EPID quality control are listed in Table 1. These standards consist of a series of tests to be performed, along with their minimum frequency. The tests are derived from the published literature and, in particular, the standards laid out in the AAPM document, TG 58 (AAPM, 2001) and the IPEM document, Report 81 (IPEM, 1999). The Tolerance Level is typically set at 50-75% of the Action Level.

The tests should be performed by a qualified medical physicist, or a suitably trained individual working under the supervision of a qualified medical physicist. Independent verification of the results of quality control tests is an essential component of any quality control program. To ensure redundancy and adequate monitoring, a second qualified medical physicist must independently verify the implementation, analysis and interpretation of the quality control tests at least annually. This independent check must be documented.

Daily tests must be scheduled prior to patient treatments. For other tests, testing at less than the minimum frequency is permissible only if experience has established that the parameters of interest are highly stable. Documentary evidence supporting this decision is essential. It is unlikely that a frequency of less than half that specified here could be justified.

In the event that the equipment does not meet the stated performance objectives and criteria an adjustment or repair should be effected. If it is not possible to restore the equipment to full performance immediately, then the use of the equipment must be restricted to clinical situations in which the identified inadequate performance is of no or acceptable and understood clinical significance. The decision on the most appropriate response is made by the supervising physicist in conjunction with the users of the equipment and others as appropriate

Preventive maintenance schedules and interventions are recommended by the manufacturer of the equipment and should be adhered to diligently. Following preventive maintenance or repair, the appropriate quality control tests selected from those listed in Table 1 must be performed before the unit is returned to clinical service. The extent of testing required must be judged by a qualified medical physicist. Frequently, equipment repairs and quality control testing are performed by different individuals. In such cases, good communication and reporting between the various staff involved are essential.

As pointed out previously, radiation safety activities are beyond the scope of this report. However, such activities may be integrated into routine quality control programs of equipment.

Documentation

Appropriate documentation is an essential component of a quality assurance program. All documents associated with the program should contain, as a minimum, the following information:

1. the name of the institution
2. the name of the originating department
3. the name(s) of the document's author(s)
4. the name of the individual(s) or group who approved the document for clinical use
5. the date of first issue
6. the number and date of the current revision

Further guidelines on the design of appropriate documentation may be found elsewhere (ISO, 1994, Quality, 2000)

Documents for use in a quality control program may be conveniently separated into two major categories: protocols and records. The protocols must be included in the Policy and Procedure Manual of the Radiation Treatment Quality Assurance Committee.

The quality control protocol contains the standards, or performance objectives and criteria, to be applied to the piece of equipment. Such standards are based on documents such as this. In addition to the specification of standards, the protocol should provide sufficient detail on the test equipment and procedures to be followed that there can be no residual ambiguity in the interpretation of the test results.

The quality control record contains the results of the tests, the date(s) on which they were performed and the signatures and qualifications of the tester and the supervising physicist. When the number of tests to be performed on a particular occasion is limited and the test procedure is simple it may be advantageous to combine the protocol and record into a single document.

In addition to the protocol and record, it is essential to have a means of documenting any corrective action that takes place together with any subsequent tests. Deviations from the locally approved protocol, such as those resulting from clinical pressure to access the equipment, must, of course, also be documented.

It is also necessary to maintain appropriate records of education, training, skills and experience of those involved with any aspect of the quality control program.

The documentation may be in any form of type of medium according to institutional policies.

Finally, all documentation related to the quality control program must be retained for at least ten years

Table 1: Quality Control Tests

Designator	Test	Performance	
		Tolerance	Action
Daily			
DE1	Mechanical integrity	Functional	
DE2	Electrical integrity	Functional	
DE3	Collision interlocks	Functional	
DE4	Image quality	Reproducibility	
Monthly			
ME1	Positioning in the imaging plane	1	2
ME2	Positioning perpendicular to the imaging plane	10	20
ME3	Image quality	Reproducibility	
ME4	Artifacts	Reproducibility	
ME5	Spatial distortion	1	2
ME6	Monitor controls	Reproducibility	
ME7	Records	Complete	
Six monthly			
SE1	Spatial resolution	Reproducibility	
SE2	Noise	Reproducibility	
SE3	On screen measurement tools	0.5	1
SE4	Set-up verification tools	0.5, 0.5^{o}	1, 1^{o}
Annually			
AE1	Independent quality control review	Complete	

Tolerances and Action Levels are specified in millimetres unless otherwise stated

Notes

Daily Tests

DE1 The imager must be visually inspected for loose or damaged components.

DE2 The imager must be inspected for loose connectors, frayed cables or any other potential electrical hazard.

DE3 All collision prevention devices must be tested for correct operation.

DE4 A contrast detail phantom must be imaged using the established standard dose for the phantom at available x-ray energies and the most commonly used acquisition mode. Visibility of the holes is compared with those imaged and regarded as acceptable at acceptance testing.

Monthly Tests

ME1	Alignment of the mechanical centre of the imager with the axis of collimator rotation must be established at the four cardinal gantry angles.
ME2	The distance of the imager from the X-ray source (or isocentre) must agree with that set or indicated.
ME3	A contrast detail phantom must be imaged using the established standard doses for the phantom at available x-ray energies and all clinically used acquisition modes. Visibility of the holes is compared with those imaged and regarded as acceptable at acceptance testing.
ME4	Bars, lines or other artifacts should be absent.
ME5	Spatial distortion across the imager is determined using a large grid.
ME6	The monitor on which the images are viewed must be checked for optimum focus and appropriate brightness and contrast for the viewing conditions
ME7	Documentation relating to the daily quality control checks, preventive maintenance, service calls and subsequent checks must be complete and legible.

Six Monthly Tests

SE1	Using a high contrast bar pattern, or some similar device, the spatial resolution of the imager is measured at least three representative positions and the values compared with those measured at acceptance (for video based systems only).
SE2	An image of a uniform thickness attenuator is obtained under a standard exposure condition. Using the imager's software, the standard deviations of pixel values in three or more predefined regions of interest are compared with the values measured at acceptance.
SE3	A geometrically accurate phantom is used to compare the system's estimate of distance with the true distance. The comparison should be made in orthogonal directions and at several locations in the imaging plane. The Tolerance and Action Levels may need to be modified to accommodate the actual pixel size of the unit of interest
SE4	Software tools which report spatial discrepancies between images should be checked for accuracy.

Annual Tests

AE1	To ensure redundancy and adequate monitoring, a second qualified medical physicist must independently verify the implementation, analysis and interpretation of the quality control tests at least annually.

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