Canadian Association of Provincial Cancer Agencies

Standards for Quality Control at Canadian Radiation Treatment Centres

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Multileaf Collimators

March 2006

Developed, revised and submitted for approval by THE CANADIAN ORGANIZATION OF MEDICAL PHYSICS and THE CANADIAN COLLEGE OF PHYSICISTS IN MEDICINE

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Document development and review process: The quality control documents in this series originated from one of two sources. Some of the source documents, such as this, were commissioned by CAPCA specifically for the purpose of developing national standards. Others as this, 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 was 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. Extensive 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 ($\mu Gy\ m^2/h$)
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 measures for use with multileaf collimators. It was specially commissioned for the CAPCA initiative.

A quality control program on equipment used for 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 a physicist 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, appropriate documentation, appropriate remedial actions and communication with other relevant parties on 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 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 equipment and procedures are sufficiently sensitive to establish compliance or otherwise with the objectives and criteria specified here.

Radiation safety activities are beyond the scope of this report. However, such activities may be integrated into routine quality control programs of 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 continuous 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, feedback and review.

The standards promoted in this document are based on the experience of the authors and reviewers and are broadly consistent with recommendations from other

jurisdictions (AAPM, 1994; 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: Systems for which the criterion of performance is "Functional" are either working 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. Reproducibility: 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. An example is field flatness. For characteristics that are not readily amenable to quantification on a routine basis, such as image quality, criteria have to be developed locally to reflect the test equipment available and inter or intra-observer variability as appropriate.

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 procedures, analysis and documentation.

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

i. Tolerance Level: For a performance parameter which can be measured, a tolerance level is defined. If the difference between the measured value and its expected 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 on 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 intervention 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.

System Description

Multileaf Collimators (MLC) are computer-controlled devices that are capable of providing photon beam shielding for linear accelerators using high density leaves (typically tungsten alloy) which are projected into the radiation field. Multileaf Collimators have a number of uses in radiation therapy, the primary being to replace conventional mounted blocks for critical organ shielding. When used in this manner MLC's eliminate the need for mounted block manipulation and storage, and the computer controlled nature of the device means that changes in the blocking pattern can be easily produced. A secondary use of MLC's is in the production of intensity modulated beams. By adjusting the position of the MLC in the radiation field during the beam-on time, an arbitrary dose distribution may be achieved. There are various approaches to intensity modulation which are beyond the scope of this document.

Current MLC systems vary with respect to design, location and use (Das, 1998; Boyer, 1996; Boyer, 1999). They may be installed as a tertiary device below the secondary collimators, or they may comprise a total or partial replacement of the secondary collimators. The leaves must provide an acceptable degree of beam attenuation, provide a large enough field coverage, and must be well integrated with the rest of the collimator shaping system. In order to minimize penumbra various design considerations have been devised by manufacturers to provide focussed field shaping.

Computer control is a key component of the MLC. There must be feedback on the leaf position, and beam interlock capabilities when leaf misplacement is detected. In addition there must be interlock capabilities to detect leaf carriage positions that could lead to unintentional irradiation outside the shielded area. Other safety interlocks must recognize the unintentional use of the MLC in electron mode, and incorporate the use of the MLC in port-film mode.

The MLC will often be linked into a department-wide computer network whereby the MLC computer file may be first produced on a treatment planning computer, prepared for the linac with a proprietary workstation, then sent to a record and verify computer which may be interfaced with the linac control system.

The current MLC is a beam-shaping device comprising sophisticated mechanical and electronic components which are moved and monitored under computer control. MLC's are changing from simple beam shaping devices to both spatial and temporal radiation beam modifiers for intensity modulated radiation therapy, and it is likely that they will become a standard feature of all linear accelerators in the near future.

MLC technology and usage are under constant evolution. From the original intent of replacing heavy metal blocks, MLCs have been used to replace compensating filters in much the same way that jaw motion leads to dynamic wedges. The enhanced integration of MLC systems with the dose monitoring systems of a linac effectively allows the development of intensity-modulated radiation therapy (IMRT). **The IMRT aspects of MLC usage, however, will be covered in another CAPCA Quality Control Standard.**

The present standards relate to the use of MLC's as simple beam shaping devices. Still, MLC technology and usage are developing rapidly, requiring the establishment of definitive guidance on the quality control aspects of MLCs. We now briefly summarize the design features of the main MLC systems available on the market.

There are a wide variety of commercial MLC configurations. Some designs may involve the replacement of the upper or lower pair of conventional accelerator jaws while others involve the addition of an MLC to both of the conventional jaws. Still other configurations involve no conventional jaws at all. MLC designs involving upper or lower jaw replacement influence the monitor unit calculation as the proximity of the MLC to the flattening filter is sufficient to obscure part of the extra-focal radiation.(Palta, 1996; Sharpe, 1995)

MLC's can be made divergent in one or two directions. This is achieved by making leaf sides match field divergence and by the course of individual leaf travel. When the latter feature is not available in a design, manufacturers mimic divergence by rounding the leaf edges.

Leaf position can also be verified by the MLC system in a variety of ways. Some use optical encoders which is useful in monitoring individual leaf position. Another design monitors leaf position by means of a CCD camera, which allows correction for gravitational sag.

Narrow beam MLCs used in slice therapy or tomotherapy are beyond the scope of the current Appendix.

Acceptance Testing and Commissioning

Multileaf collimators that are acquired with the purchase of a new accelerator or are retrofitted to an installed accelerator 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.

In addition acceptance testing of the equipment and facility will include establishing compliance with applicable radiation safety codes. These are included in federal and/or provincial regulations and it is the supervising physicist or designate's responsibility to be familiar with these requirements and to demonstrate compliance. Decommissioning of radiotherapy equipment and facilities may also be regulated by provincial and/or federal authorities.

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 multileaf collimator acceptance testing should be consistent with routine quality control objectives and criteria. In particular, there is no reason why a new or upgraded multileaf collimator, and its associated safety systems, should not meet the Tolerance Levels detailed later in this document (Table 1).

For new or retrofitted MLC installations, users are encouraged to commission in-air and in-water output factors, as well as acquire dosimetric data characterising the effect of the leaves in fields normally defined by conventional jaws. Attention should be brought to monitor unit calculations (Palta, 1996), irregularly-shaped fields (open and wedged), and IMRT. The AAPM TG-53 report provides guidelines for the validation process (AAPM, 1998). The data acquired should be consistent with the treatment planning system.

The routine quality control tests making up the present standard for multileaf collimators cannot be vendor-specific. Nevertheless, tests should cover common similar goals, from safety systems, leaf position accuracy to leaf leakage. The tests should be performed by, or under the supervision of, a qualified medical physicist.

Adherence to these standards (Table 1) should be demonstrated and documented, in or outside of the vendor's acceptance testing document, before a new MLC or major upgrade is accepted, and put into clinical service. Also, an appropriate subset of acceptance tests should be performed after any repair or preventive maintenance interventions on the device. The extent of testing required should 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.

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.

Commissioning an MLC prior to clinical use is generally left up to the medical physicist. These tests are usually directed towards integrating the MLC into clinical use, and will measure and test all aspects relating to dose distributions and beam-time calculations. Commissioning requires more extensive tests than those conducted during the acceptance testing procedure. Clinically relevant parameters related to output and penumbra will likely be investigated, and the eventual use of the MLC for IMRT may be considered. The tests listed in Table 1 comprise a minimum set that is concerned with the basic safety and functionality of the MLC when implemented as a simple blocking device. Acceptance tests must meet the tolerance values, as these values may provide a baseline for future QC testing. Specific tests will be necessary for MLC based IMRT (Burman, 1997; Curtin-Savard, 1999; Ma, 1997; Wang, 1996), and these tests are addressed in the IMRT document in this series. It is incumbent upon the medical physicist to develop and document a sensible commissioning and quality assurance program for MLC based IMRT.

Quality Control of Equipment

The purpose of a quality control program is to assure that operational standards for MLC's that were considered acceptable at 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.

The standards for multileaf collimator quality control are listed in Table 1. These minimum standards consist of tests to be performed, along with their minimum frequency. The tests are derived from the published literature some of which will be found in the References and Bibliography at the end of this document.(Casebow, 1999; Kutcher, 1994) 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 at the beginning of each working day. 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 immediately possible to restore the equipment to full performance, 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, machine repairs and quality control testing are performed by different persons. In such cases, good communication and reporting between the various staff involved are essential.

Specific tests required for MLC-based IMRT will be addressed in a separate standards document.

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 of the developer of the document
4. the name of the individual 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, 2000; 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.

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

Table 1: Quality Control Tests for Multileaf collimators

Designator	Test	Tolerance	Action Level
Patient-specific			
PM1	Verification of transferred data vs printed template	1	2
PM2	Daily verification of correct data	Reproducibility	
PM3	Verification of record & verify programming	Reproducibility	
Monthly			
MM1	Digitizer check (if used)	Functional	
MM2	Light and radiation field coincidence	1	2
MM3	Leaf positions for standard field template	1	2
MM4	Electron field interlocks	Functional	
MM5*	Leaf alignment		1
MM6	Records	Complete	
Yearly			
AM1	Leaf transmission (all energies)	Reproducibility	
AM2	Leakage between leaves (all energies)	Reproducibility	
AM3*	Transmission through abutting leaves	Reproducibility	
AM4	Stability with gantry rotation	Reproducibility	
AM5	Alignment with jaws		1
AM6	Independent quality control review	Complete	

* May not apply to all MLC designs.

Tolerances and action levels are specified in millimetres unless otherwise stated

Notes

Daily Tests

PM1 Comparison of the optical projection of the MLC field with a template, usually an appropriately-scaled printout of a DRR or a BEV.

PM2 Daily comparison of a template with corresponding field on MLC monitor.

PM3 Verification of the programming of record-and-verify systems prior to first treatment.

Monthly Tests

MM1 This test may become obsolete as MLC positions are determined by treatment planning software.

MM2 For MLCs with rounded leaf edges, the optical field may be smaller than the radiation field. A standard irregular shaped field may be verified.

	Alternatively, step-and-shoot sequences may be programmed to verify the positional accuracy through the course of individual leaves.
MM3	Light projection of an irregular MLC shaped field involving all leafs onto a standard template. The displayed leaf positions should match those of the x-ray field.
MM4	Verify that electron beams cannot be turned on unless leaves are retracted.
MM5	Verify the calibration of the position of each leaf in relation to the others. May be part of routine MLC maintenance.
MM6	Documentation relating to the daily quality control checks, preventive maintenance, service calls and subsequent checks must be complete, legible and the operator identified.

Yearly tests

AM1,2,3	Best achieved with film. Average and maximal transmission should be reported.
AM4	With the gantry at 90 or 270 degrees, irradiate film placed at isocentre with long, narrow field defined by MLC. Exposures should be made with the leaves vertical and the collimator rotated ± 60 degrees.
AM5	Use a large field with one leaf from each leaf bank protruding well into the field. The parallelism with the collimator edge is checked on film.
AM6	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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