

Canadian Partnership for Quality Radiotherapy
Technical Quality Control Guidelines
for Medical Linear Accelerators and Multileaf Collimators

A guidance document on behalf of:
Canadian Association of Radiation Oncology
Canadian Organization of Medical Physicists
Canadian Association of Medical Radiation Technologists
Canadian Partnership Against Cancer

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Introduction

The Canadian Partnership for Quality Radiotherapy (CPQR) is an alliance amongst the three key national professional organizations involved in the delivery of radiation treatment in Canada: the Canadian Association of Radiation Oncology (CARO), the Canadian Organization of Medical Physicists (COMP), and the Canadian Association of Medical Radiation Technologists (CAMRT). Financial and strategic backing is provided by the federal government through the Canadian Partnership Against Cancer (CPAC), a national resource for advancing cancer prevention and treatment. The mandate of the CPQR is to support the universal availability of high quality and safe radiotherapy for all Canadians through system performance improvement and the development of consensus-based guidelines and indicators to aid in radiation treatment program development and evaluation.

This document contains detailed performance objectives and safety criteria for *Medical Linear Accelerators and Multileaf Collimators*. Please refer to the overarching document *Technical Quality Control Guidelines for Canadian Radiation Treatment Centres*⁽¹⁾ for a programmatic overview of technical

quality control, and a description of how the performance objectives and criteria listed in this document should be interpreted.

System Description

Medical linear accelerators (linacs) are cyclic accelerators which accelerate electrons to kinetic energies from 4 MeV to 25 MeV using non-conservative microwave radio frequency (RF) fields in the frequency range from 10^3 MHz (L band) to $\sim 10^4$ MHz (X band), with the vast majority running at 2856 MHz (S band).⁽²⁻⁵⁾ In a linear accelerator the electrons are accelerated following straight trajectories in special evacuated structures called accelerating waveguides. Electrons follow a linear path through the same, relatively low potential difference several times; hence, linacs also fall into the class of cyclic accelerators just like the other cyclic machines that provide curved paths for the accelerated particles (e.g., betatron). The high power RF fields used for electron acceleration in the accelerating waveguides, are produced through the process of decelerating electrons in retarding potentials in special evacuated devices called magnetrons or klystrons.

Various types of linacs are available for clinical use. Some provide x rays only in the low megavoltage range (4 MV or 6 MV) while others provide both x rays and electrons at various megavoltage energies. A typical modern high-energy linac will provide two or three photon energies (usually a combination of a low [4 to 10 MV] and a high [12 to 25 MV] photon beam) and several electron energies (ranging from 4 to 22 MeV).

Included in the scope of this document are multileaf collimators (MLCs); computer-controlled devices capable of providing photon beam shielding for linear accelerators using high density leaves (typically tungsten alloy) which are projected into the radiation field.⁽⁶⁻⁸⁾ In addition to static beam shaping, beam intensity modulation can also be achieved by adjusting the position of the MLC in the radiation field between treatment fields (step and shoot, or static intensity-modulated radiation therapy [IMRT]), by moving the leaves across the field with varying velocities during the beam-on time (dynamic IMRT), or by varying the dose rate, gantry speed, and MLC leaf positions during arc delivery (volumetric modulated arc therapy [VMAT]). By doing this, a desired fluence pattern can be approximated within certain physical limits.

Current MLC systems vary with respect to design, location, and use. 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 focused field shaping.

Computer control is a key component of the MLC, particularly during the delivery of dynamic treatments. There must be feedback on the leaf position and beam interlock capabilities when leaf misplacement is

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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.

Related Technical Quality Control Guidelines

In order to comprehensively assess medical linear accelerator performance, additional guideline tests, as outlined in related CPQR Technical Quality Control (TQC) guidelines must also be completed and documented, as applicable. Related TQC guidelines, available at cpqr.ca, include:

- Safety Systems
- Major Dosimetry Equipment
- Accelerator-Integrated Cone-Beam Systems for Verification Imaging
- Patient-Specific Dosimetric Measurements for Modulated Therapies

Test Tables

Table 1: Daily Quality Control Tests

Designator	Test	Performance	
		Tolerance	Action
Daily			
DL1	Motion interlock	Functional	
DL2	Couch brakes	Functional	
DL3	Beam interrupt/counters	Functional	
DL4	Lasers/crosshairs	1 mm	2 mm
DL5	Optical distance indicator	1 mm	2 mm
DL6	Optical back pointer	2 mm	3 mm
DL7	Field definition: Jaws/MLC leaves	1 mm	2 mm
DL8	Output constancy – photons	2%	3%
DL9	Output constancy – electrons	2%	3%
DL10	Dynamic (Varian), Virtual (Siemens) or Universal (Elekta) wedge factors	2%	3%

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Notes on Daily Tests

- DL1 This test establishes that motion-enabling features on the linac (e.g., those that allow the gantry to rotate only under desired conditions) are operational. These include functionality tests of couch and hand-pendent controls and the proper engagement of collision interlocks when touch guards are engaged.
- DL2 A functional test is performed to establish that brakes on the treatment couch engage when desired and prevent the couch from floating freely or moving when a small force is applied.
- DL3 This test demonstrates (when applicable): the key interlock prevents the linac from irradiating; the non-emergency beam interruption system stops the beam; and the beam terminates after a predefined number of monitor units as verified by a backup monitor unit counter and/or timer if applicable.
- DL4 This test establishes the alignments of crosshairs with appropriate lasers are within the specified limits.
- DL5 At gantry angle 0°, the test demonstrates that the optical distance indicator identifies the isocentre plane within the specified limits.
- DL6 This test verifies the performance accuracy of the optical back pointer for applicable units.
- DL7 Gantry angle 0°, 100 cm source-axis distance (SAD). This test demonstrates the field edges are accurately defined by jaws and/or MLC leaves. It is sufficient to confirm a predefined field shape using the projected light field at isocentre. Tolerance and action levels apply to each edge of a rectangular field at isocentre as defined by the jaws/MLC leaves. Note that systems with a tertiary collimation MLC system will require both jaw and MLC leaf positions to be verified.
- DL8 Output constancy must be verified for all photon energies in use on the particular treatment day. Measurement is to be conducted using standard local geometry using a dosimetry system calibrated against the local secondary standard system.
- DL9 Output constancy must be verified for all electron energies in use on the particular treatment day. Measurement is to be conducted using standard local geometry using a dosimetry system calibrated against the local secondary standard system.
- DL10 Wedge factors for a representative set of dynamic or virtual soft wedges in use on a particular treatment day must be verified. Machine design characteristics must be

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considered when determining the representative set. Alternatively, a test cycle designed to test the full range of wedges over multiple days may be considered. Daily wedge factors for universal wedges are required to ensure functionality and position reproducibility.

Table 2: Monthly Quality Control Tests

Designator	Test	Performance	
		Tolerance	Action
Monthly			
ML1	Wedge, tray, cone, interlocks	Functional	
ML2	Accessories integrity and centring	Functional	
ML3	Gantry angle readouts	0.5°	1.0°
ML4	Collimator angle readouts	0.5°	1.0°
ML5	Cross-hairs centring/collimator rotation isocentre (mechanical)	1 mm	2 mm
ML6	Couch position readouts	1 mm	2 mm
ML7	Couch rotation isocentre (mechanical)	1 mm	2 mm
ML8	Couch isocentric angle	0.5°	1.0°
ML9	Optical distance indicator	1 mm	2 mm
ML10	Relative dosimetry	2%	3%
ML11	Central axis depth dose reproducibility	1%/2 mm	2%/3 mm
ML12	Beam profile constancy	2%	3%
ML13	Light/radiation coincidence	1 mm	2 mm
ML14	Jaw position accuracy	1 mm	2 mm
ML15	Backup jaw position accuracy (Elekta)	1 mm	2 mm
ML16	MLC leaf position accuracy	1 mm	2 mm
ML17	Dynamic leaf position accuracy (picket fence)	0.5 mm	1 mm
ML18	Dynamic MLC fluence delivery	95% ≤ 3%/3 mm	95% ≤ 5%/3 mm
ML19	Variation of dose rate, gantry speed, MLC leaf speed and position during arc delivery	See note: ML19	See note: ML19
ML20	Records	Complete	

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Notes on Monthly Tests

- ML1 Verify the functionality of latching interlocks (includes verification that electron beams cannot be turned on unless the MLC leaves are retracted).
- ML2 Verify the physical integrity and centring of accessories, including wedges, trays, and cones, as appropriate.
- ML3 The accuracy of the digital and mechanical (if used clinically) gantry angle readouts must be verified for at least 0°, 90°, 180°, and 270°. The coordinate system convention should also be verified.
- ML4 The accuracy of the digital and mechanical (if used clinically) collimator angle readouts must be verified for at least 0°, 90°, 180°, and 270°. The coordinate system convention should also be verified.
- ML5 This test establishes the correct centring of the crosshairs as well as the mechanical axis of rotation of the collimator. Tolerance and action levels refer to the maximum diameter of the mechanical isocentre and the maximum displacement of the crosshairs projection from the centre of the mechanical isocentre circle.
- ML6 Mechanical and digital couch position readouts must be verified over an appropriate clinical range in the directions of the three cardinal axes. Also verify coordinate system convention.
- ML7 Isocentric rotation of the couch about the collimator rotation axis must be verified. Similar to ML5, the tolerance and action levels refer to the maximum displacement of crosshairs projection from the initial position in the isocentre plane.
- ML8 Mechanical and digital couch isocentric rotation angle readouts must be verified over the applicable clinical range. Also verify coordinate system convention.
- ML9 A mechanical device, calibrated against the true radiation isocentre, is used to provide the base reading for the check of the optical distance indicator. The standards stated in the Table apply at the isocentre. The optical distance indicator should be checked over a clinically relevant range of source-to-skin distances (SSDs) and gantry angles. The tolerance and action levels may be twice as large (i.e., 2 mm and 4 mm) at the clinical limits of the optical distance indicator's range.
- ML10 Using a dosimetry system calibrated against the local secondary standard, the output of all clinical beams is checked against yearly reference dosimetry.

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- ML11 Measurements are made to confirm that the depth dose has not changed since commissioning the unit. Tolerance and action levels are specified in percentages for photon beams and in millimetres for electron beams. A single ratio of doses taken at clinically relevant depths is sufficient for these measurements. Alternatively, a tissue-phantom ratio (TPR) measurement or a check of profile constancy at a shallow depth could be used, and the tolerance and action levels adjusted appropriately.
- ML12 This test replaces testing of flatness and symmetry and is intended to be consistent with the testing suggested in American Association of Physicists in Medicine (AAPM) protocol TG-142.⁽⁹⁾ The goal is to ensure that profiles are delivered in a manner consistent with that modelled in the associated treatment planning system. Tolerance and action levels refer to differences from commissioning (or baseline) profiles as defined in the AAPM protocol TG-142.⁽⁹⁾ Separate tests are required for all clinically applicable beams.
- ML13 Geometric alignment of the radiation and optical field edges must be established over a range of field sizes. Tolerance and action levels apply to each edge of a rectangular field.
- ML14 Accuracy of the radiation position of the jaw must be established over a range of jaw positions. The number of positions tested shall be determined from the jaw calibration method. In conjunction with this test it is important to establish acceptable dose profiles for abutting fields at the 0 position. Here the 2 mm action level for each jaw is generally not sufficient since in principle, abutting fields could have a difference of up to 4 mm between field edges, which can lead to unacceptable peaks or valleys in dose distributions. A tolerance of 5% and an action level of 10% in dose profile deviations for abutting fields are suggested.
- ML15 Accuracy of the radiation position of the backup jaw must be established over a range of positions. The number of positions tested shall be determined from the jaw calibration method.
- ML16 Accuracy of the radiation position of the MLC leaf edges must be established over a range of MLC positions. The number of MLC positions tested shall be determined from the MLC calibration method. For some MLC designs this test may be accomplished by evaluating the radiation position of each leaf relative to a reference leaf.
- ML17 For dynamic MLC IMRT, leaf gap accuracy for all leaf pairs is verified via inspection of a two-dimensional dose map of a picket fence pattern delivered at gantry angle of 0°.
- ML18 Specific to IMRT, this test demonstrates that the interplay of leaf velocity, gap width, gap position, and beam holds combine to deliver a planar dose map consistent with the

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prediction of the treatment planning system. A test plan should consider extreme conditions (e.g., the highest levels of modulation used clinically for each leaf pair). An acceptable alternative to this test is the regular (more than once per month) measurement of patient-specific, dynamic MLC IMRT fields. Tolerance and action levels are defined via the gamma metric comparing dose map differences (plan versus measurement). Dose maps are defined with region of interest threshold of 10% of the maximum dose. Dose differences are global (i.e., with respect to maximum dose).⁽¹⁰⁾ Detector resolution must be sufficient to identify performance of individual leaves. As with all tests, tolerance and action levels may be tightened at the user’s discretion.

ML19 The synchronicity of all dynamic parameters during arc delivery. Parameters may be evaluated independently, using a subset of the tests described by Ling et al.⁽¹¹⁾ or Bedford and Warrington,⁽¹²⁾ or by the repeat delivery of a standard VMAT plan of suitable complexity, similar to test ML18. Tolerance and action levels are in reference to the consistency of dose delivered at different dose rate, gantry or MLC speeds. Tolerance levels should be based on the performance of the linear accelerator, whereas action levels should be set to achieve an overall precision consistent with other monthly tests (approximately 3%/2 mm from baseline).

ML20 Documentation relating to the daily quality control checks, preventive maintenance, service calls, and subsequent checks must be complete, legible, and the operator identified.

Table 3: Annual Quality Control Tests

Designator	Test	Performance	
		Tolerance	Action
Annual			
AL1	Profile reproducibility	2%	3%
AL2	Depth dose reproducibility	1%	2%
AL3	Reference dosimetry	1%	2%
AL4	Relative output factor reproducibility	1%	2%
AL5	Wedge transmission factor reproducibility	1%	2%
AL6	Accessory transmission factor reproducibility	1%	2%
AL7	Wedge profile reproducibility	1%	2%
AL8	Profile and output reproducibility versus gantry angle	1%	2%

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AL9	Monitor chamber linearity	1%/1 MU	2%/2 MU
AL10	End monitor effect	0.5 MU	1 MU
AL11	Collimator rotation isocentre (radiation)	1 mm	2 mm
AL12	Gantry rotation isocentre (mechanical and radiation)	1 mm	2 mm
AL13	Couch rotation isocentre (radiation)	1 mm	2 mm
AL14	Coincidence of radiation and mechanical isocentres	1 mm	2 mm
AL15	Coincidence of axes of rotation	1 mm	2 mm
AL16	Couch deflection	3 mm	5 mm
AL17	Leaf transmission (all energies)	1%	2%
AL18	Leakage between leaves (all energies)	2%	3%
AL19	Transmission through abutting leaves	2%	3%
A20	MLC leaf alignment with jaws	0.5°	1°
A21	Dosimetric leaf gap	0.2 mm	0.3 mm
AL22	Independent quality control review	Complete	

Notes on Annual Tests

- AL1 This test establishes that an appropriate subset of the crossplane and inplane profiles at gantry angle 0° are consistent with water-tank measurements made at the time of commissioning. Tolerance and action levels refer to differences from commissioning or baseline. Measurements should be made for all clinically operable beams.
- AL2 Depth dose scans necessary for calibration protocols (alternatively TPR measurements) are also made and used to verify consistency with commissioning/baseline water-tank measurements. Tolerance and action levels refer to differences from commissioning or baseline. Measurements should be made for all clinically operable beams.
- AL3 A full absolute dosimetry output calibration based on an internationally accepted protocol (e.g., AAPM TG-51)⁽¹³⁾ must be performed annually on each energy used clinically for both photons and electrons. Independence of output with respect to dose rate (pulse repetition frequency) must also be established across clinically applicable dose rates.

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- AL4 An appropriate subset of relative output factors are confirmed to be consistent with commissioning measurements.
- AL5 The wedge transmission factors (if applicable) are confirmed to be consistent with commissioning measurements.
- AL6 Transmission factors are confirmed to be consistent with commissioning measurements. Discretion may be used. Devices where the physical composition/dimension can be confirmed not to have changed since a previous measurement need not be measured again.
- AL7 This test applies to moving jaw (dynamic and virtual) and universal (Elekta) wedges. This test confirms that wedged fields produce profiles that are consistent with baseline data through the central 80% of the field for all clinically used wedge angles.
- AL8 This test establishes the independence of output with gantry angle. It requires that output be measured under identical conditions (e.g., dosimeter under the same amount of buildup material in each position) and that the difference from the gantry at 0° position be within the specified limits. In addition to central axis output, beam profiles shall be measured at three cardinal gantry angles: 0°, 90°, and 270°. Measurements should be made for all clinically operable beams.
- AL9, 10 From a series of radiation measurements with different monitor units the linearity and the end monitor effect are determined. The larger of the percentage or absolute value is taken as what is applicable. Measurements should be made for all clinically operable beams.
- AL11 Commonly measured using a star shot technique this test determines the diameter of the circle that encompasses the radiation isocentre of the collimator as it is rotated through an appropriate sample of angles within its full range of motion. The diameter must be within specifications.
- AL12 This test determines the diameter of both the mechanical and the radiation isocentre defined by gantry rotation through its full clinical range of motion. Each diameter must be within specifications.
- AL13 This test determines the diameter of the radiation isocentre defined by couch rotation through its full clinical range of motion. The diameter must be within specifications.
- AL14 The coincidence of radiation and mechanical isocentres is established for the collimator, gantry and couch; and must meet the specified limits.

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- AL15 The three axes of rotation (the collimator/MLC, the couch, and the gantry) must meet within a sphere of the specified diameter.
- AL16 Couch deflection is measured as a difference in surface position (load versus no load) of the couch extended longitudinally at least 30 cm through isocentre. Under “load” is considered as a typical patient mass (approximately 70 kg) distributed over the couch or placed at the centre. Tolerance and action levels are defined relative to the deflection measured at the time of commissioning.
- AL17 The average and maximum MLC leaf transmission is verified in this test for all photon energies and compared with the values established at the time of commissioning or the values adopted in the treatment planning system. Tolerance and action levels refer to changes from the commissioning measurements.
- AL18 The average and maximum leakage between adjacent, closed MLC leaves is verified in this test for all photon energies and compared with the values established at the time of commissioning or the values adopted in the treatment planning system. Tolerance and action levels refer to changes from the commissioning measurements.
- AL19 The average and maximum leakage between abutting closed MLC leaves is verified in this test for all photon energies and compared with the values established at the time of commissioning or the values adopted in the treatment planning system. Tolerance and action levels refer to changes from the commissioning measurements.
- AL20 Use a leaf pattern where one leaf from each leaf bank protrudes well into the field. Confirm the leaf edge parallelism with the collimator or solid jaw edge.
- AL21 A dynamic leaf gap test (sometimes referred to as a dosimetric leaf gap test) is performed to confirm consistency with baseline measurements. The minimum standard is to establish this using a single detector (e.g., an ion chamber) method, although methods that calculate separate factors for each leaf pair may be employed. The value should be consistent within tolerance for all four cardinal gantry angles.
- AL22 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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