

COMP report: CPQR technical quality control guidelines for kilovoltage X ray radiotherapy machines

Christophe Furstoss

Département de Radio-Oncologie, Hôpital
Maisonneuve-Rosemont, Montréal, QC,
Canada

Author to whom correspondence should be
addressed. Christophe Furstoss
E-mail: cfurstoss.hmr@ssss.gouv.qc.ca;
Telephone: (514) 252 3400 extension 7838

[Correction added on 12th February 2018,
after first online publication: CQPR in the
title was corrected to CPQR]

Abstract

The Canadian Organization of Medical Physicists (COMP) in close partnership with the Canadian Partnership for Quality Radiotherapy (CPQR) has developed a series of Technical Quality Control (TQC) guidelines for radiation treatment equipment. These guidelines outline the performance objectives that equipment should meet in order to ensure an acceptable level of radiation treatment quality. The TQC guidelines have been rigorously reviewed and field tested at various Canadian radiation treatment facilities. The development process enables rapid review and update to keep the guidelines current with changes in technology (the most updated version of this guideline can be found on the CPQR website). This particular TQC details recommended quality control for kilovoltage X Ray radiotherapy machines.

PACS

87.55.Qr

KEY WORDS

kilovoltage, quality control, radiotherapy.

1 | INTRODUCTION

The Canadian Partnership for Quality Radiotherapy (CPQR) is an alliance among 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 Kilovoltage X Ray Radiotherapy Machines. Please

refer to the overarching document Technical Quality Control Guidelines for Canadian Radiation Treatment Centres¹ 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.

All information contained in this document is intended to be used at the discretion of each individual center to help guide quality and safety program improvement. There are no legal standards supporting this document; specific federal or provincial regulations and license conditions take precedence over the content of this document.

2 | SYSTEM DESCRIPTION

Kilovoltage radiotherapy units, although eclipsed first by ⁶⁰Co irradiators and then by linear accelerators, remain useful in the mix of

energies available to a radiotherapy program. Low-energy X ray beams have application in the treatment of skin lesions and shallow tumors. The quality assurance program for the kilovoltage units must match the rigor of that for the most modern irradiators and is every bit as important in order to safely deliver an accurate dose to the patient for those lesions they are appropriate to treat.

Application of kilovoltage radiotherapy is divided into two categories based on the chosen tube voltage. The lower energy range (the “superficial” range; X ray tube potentials of 30 kVp or 40 kVp to 100 kVp and tube currents of a few milliamperes) is used to treat surface lesions. Filtration of up to 6 mm of Al is added to remove the very low energy photons and “harden the beam.” Applicator cones, attached directly to the tube-housing head, are the usual method by which the irradiation area is defined. Variable collimators are also available on some units and require additional quality control tasks over those performed for applicators. Treatment is performed at short source-to-surface distance (SSD) (e.g., less than 20 cm) and the lesion depth must be less than a few millimeters. Therefore, the “kilovoltage” range is selected when surface to shallow lesions are treated. In so doing, tissue greater than that at a moderate depth is spared when treating surface lesions.

“Orthovoltage” therapy refers to radiation treatment using X ray tube potentials in the 100–300 kVp range, although 200–300 kVp may be the more practical specification. This deeper radiotherapy equipment uses beam currents of up to 20 mA and applied filtration equivalent to produce half-value layer (HVL) values of 0.1–4 mm Cu. Coned applicators or movable diaphragms are used to define these beams. While coned applicators may be constructed mostly of metal (e.g., Cu), they have a clear plastic end to aid in viewing the target region. Hence, attention must be given to the integrity of the plastic portion. The depth dose distribution in the orthovoltage energy range is dependent on factors such as kVp, HVL, SSD, and field size. Maximum dose occurs close to the skin, with 90% of the dose being delivered within a tissue depth (water depth) of 2 cm.

Detailed descriptions of various types of kilovoltage X ray radiotherapy machines and various quality control tests have been published in the literature.^{2–26}

3 | RELATED TECHNICAL QUALITY CONTROL GUIDELINES

In order to comprehensively assess kilovoltage X ray radiotherapy machines 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:

1. Safety Systems
2. Major Dosimetry Equipment

4 | TEST TABLES (TABLES 1–4)

TABLE 1 Daily quality control tests.

Designator	Test	Performance	
		Tolerance	Action
Daily			
DK1	kVp and mA indicators	Functional	
DK2	Beam-off at key-off test	Functional	
DK3	Beam interrupt	Functional	
DK4	Backup timer/monitor unit channel check	1%	2%
DK5	Dosimetric test: output check	2%	4%

Notes on daily tests

DK1	Functional check of kVp and mA indicators
DK2	Functional check of beam-off at key-off
DK3	Functional check of the beam interrupt button (radiation stop and restart when the radiation on button is pressed again)
DK4	Quantitative verification of correct operation of backup timer or backup monitor unit
DK5	Quantitative dosimetric test: output reproducibility test at the chosen energies and filter combinations. If the output is stable with time, this test can be done weekly (so replaced by WK4 according to Table 2) on the condition that there are documents and reports to support it

TABLE 2 Weekly quality control tests.

Designator	Test	Performance	
		Tolerance	Action
Weekly			
WK1	Couch movement and brakes	Functional	
WK2	Unit motions and motion stops	Functional	
WK3	Interlocks for added filters/kVp-filter choice	Functional	
WK4	Dosimetric test: output check	2%	4%

Notes on weekly tests

WK1	Functional check of couch motion and brakes (where applicable)
WK2	Functional check of unit motions and motion stops
WK3	Functional check of interlocks for added filters, correct placement of filters, and the matching of filters with kVp value
WK4	Quantitative dosimetric test: output reproducibility test for all energies. This test can be limited to the energies used clinically on the condition that any additional energies cannot be chosen at any time (by removing the corresponding filters from the treatment room, for example)

TABLE 3 Monthly quality control tests.

Designator	Test	Performance	
		Tolerance	Action
Monthly			
MK1	Mechanical stability and safety	Functional	
MK2	Cone/filters integrity and cone indicators	Functional	
MK3	Physical distance indicators	2 mm	3 mm
MK4	Accuracy of head tilt and rotation readouts	1°	1.5°
MK5	Light/x ray field coincidence	2 mm	3 mm
MK6	Light field size	2 mm	3 mm
MK7	X ray field size indicator	2 mm	3 mm
MK8	X ray field uniformity	5%	8%
MK9	Output verification and reproducibility with head tilt and rotation	2%	4%
MK10	Timer accuracy verification	1%	2%
MK11	Dose rate output constancy	2%	4%
MK12	Records	Complete	

Notes on monthly tests

MK1	Verification that the unit and accessories are firmly anchored and may be used without endangering patients or staff
MK2	Verification of the integrity of the filters and cones and cone indicators
MK3	Verification of the optical and/or mechanical distance indicator if the unit is equipped with one
MK4	Verification of the angle readouts
MK5	Performance parameters refer to agreement at each edge. This test does not apply to all machine designs
MK6	Geometric test to verify the light field sizes (where applicable)
MK7	Confirmation of radiation field size when a variable collimation system is provided. At least two field sizes must be checked
MK8	Using a film, the flatness and symmetry of the X ray beam must be assessed for the largest cone
MK9	Quantitative dosimetric test: output reproducibility test at all energies with varying head tilt and rotation ²⁷
MK10	If the unit is equipped with a timer, its accuracy must be checked against a stop watch over a range of doses of 10–1000 cGy
MK11	Should be checked for all beam qualities for MU-based systems
MK12	Documentation relating to the daily quality control checks, preventive maintenance, service calls and subsequent checks must be complete, legible, and the operator identified

TABLE 4 Annual quality control tests.

Designator	Test	Performance	
		Tolerance	Action
Annual			
AK1	Reference dosimetry	1%	2%
AK2	Timer and end-effect error	Characterize	±0.05 min
AK3	Output linearity	n/a	1%
AK4	Output reproducibility	2%	3%
AK5	Output error associated with beam interrupt	2%	4%
AK6	Beam quality	10%	15%
AK7	Alignment of focal spots	0.5 mm	1 mm
AK8	Focal spot size	Reproducible	
AK9	Percentage depth dose verification	Characterize and document	
AK10	Profiles verification	Characterize and document	
AK11	Independent quality control review	Complete	

Notes on annual tests

AK1	Using a high-quality dosimetry system calibrated against the local secondary standard, all beams and cones in use are recalibrated
AK2	Timer and end-effect error measurement may be performed in conjunction with AK3
AK3	Output linearity measurement for a clinically used filter/cone combination at a standard SSD and a dose range of 10–1000 cGy
AK4	Output reproducibility verification for a clinically used filter/cone combination. These measurements should be repeated at typical tilt and head rotation used for treatments
AK5	Output error when the beam is interrupted during the irradiation for a clinically used filter/cone combination
AK6	The HVL of any clinically used beams is measured. The HVLs measured in millimeters of Al or millimeters of Cu as appropriate are compared with the values obtained at commissioning. These tolerances acknowledge measurement uncertainty
AK7	Focal spot—quantitative measurement, assessed relative to acceptance test value where applicable
AK8	Using a pin hole or resolution tool
AK9	Verification of percentage depth dose measurements for all used filter/cone combinations against baseline
AK10	Verification of inplane and crossplane profiles at different depths for all used filter/cone combinations against baseline
AK11	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

ACKNOWLEDGMENTS

The authors thank the many people who participated in the production of this guideline. These include the institutions that participated in External Validation Testing (BC Cancer Agency – Fraser Valley Centre, Surrey, British Columbia and CIUSSS du Centre-Ouest-de-l'Île-de-Montréal – Hôpital général juif, Montreal, Quebec); Michelle Nielsen and Normand Freniere (associate editors for COMP); COMP's Quality Assurance and Radiation Safety Advisory Committee; the COMP Board of Directors; Erika Brown, Michael Milosevic, and the CPQR Steering Committee, and all individuals that submitted comments during the community review of this guideline. The production of this manuscript has been made possible through a financial contribution from Health Canada, through the Canadian Partnership Against Cancer.

CONFLICT OF INTEREST

No conflict of interest.

REFERENCES

- Canadian Partnership for Quality Radiotherapy. Technical quality control guidelines for Canadian radiation treatment centres. 2016 May 1. Available from: <http://www.cpqr.ca/programs/technical-quality-control>
- Amdur RJ, Kalbaugh KJ, Ewald LM, et al. Radiation therapy for skin cancer near the eye: kilovoltage x rays versus electrons. *Int J Radiat Oncol Biol Phys.* 1992;23:769–779. Available from: [http://dx.doi.org/10.1016/0360-3015\(92\)90111-1](http://dx.doi.org/10.1016/0360-3015(92)90111-1)
- Belanger R, Papin PJ, editors. *University Health Physics: Health Physics Society 2003 Summer School*. Madison (WI): Medical Physics Publishing; 2003. ISBN 978-1930524156.
- Biggs P, Ma CM, Doppke K, Niroomand-Rad A, Beatty J. Kilovoltage x rays. In: Van DJ. *The Modern Technology of Radiation Oncology: A Compendium for Medical Physicists and Radiation Oncologists*. Madison (WI): Medical Physics Publishing; 1999:287–312.
- British Institute of Radiology. Central axis depth dose data for use in radiotherapy. *Br J Radiol*, Supplement no. 25. London: British Institute of Radiology; 1996. ISBN 978-0905749389.
- Bushong SC. *Radiologic Science for Technologists – Physics, Biology and Protection*, 7th edition. St. Louis (MO): Mosby Inc. 2001. ISBN 978-0323013376.
- Canadian Standards Association. Medical electrical equipment. Part 2: particular requirements for the safety of therapeutic x ray generators CAN/CSA-C22.2 no.601.2.8-92. Rexdale, Ontario. 1992.
- Gerig L, Soubra M, Dalhani D. Beam characteristics of the Therapax DXT300 orthovoltage therapy unit. *Phys Med Biol.* 1994;39:1377–1392. Available from: <http://dx.doi.org/10.1088/0031-9155/39/9/006>
- Government of Ontario. *Healing Arts Radiation Protection act*. [cited 2016 Jun 07] Toronto (ON): Publications Ontario; 1990. Available from: http://www.e-laws.gov.on.ca/html/statutes/english/elaws_statutes_90h02_e.htm
- International Atomic Energy Agency. *International Code of Practice IAEA Technical Reports Series no. 277. Absorbed Dose Determination in Photon and Electron Beams*. Vienna, Austria: International Atomic Energy Agency; 1987. ISBN 92-0-100597-0.
- International Commission on Radiation Units and Measurements. *Report 23: Measurement of Absorbed Dose in a Phantom Irradiated by a Single Beam of x or Gamma Rays*. Washington (DC): International Commission on Radiation Units and Measurements; 1973.
- Institute of Physical Sciences in Medicine. *Report no. 54: Commissioning and Quality Assurance of Linear Accelerators*. York, England. 1988. ISBN 978-0904181487.
- Khan F. *The Physics of Radiation Therapy, Second Edition, Chapter 4*. Baltimore (MA): Williams and Wilkins; 1994. ISBN 978-0683045024.
- Klevenhagen SC, Aukett RJ, Harrison RM, Moretti C, Nahum AE, Rosser KE. The IPEMB code of practice for the determination of absorbed dose for x-rays below 300 kV generating potential (0.035 mm Al–4 mm Cu HVL; 10–300 kV generating potential). *Phys Med Biol.* 1996;41:2605–2625. Available from: <http://dx.doi.org/10.1088/0031-9155/41/12/002>
- Kutcher GJ, Coia L, Gillin M, et al. Comprehensive QA for radiation oncology: report of AAPM Radiation Therapy Committee Task Group 40. *Med Phys.* 1994;21:581–618. Available from: <http://dx.doi.org/10.1118/1.597316>
- Ma CM, Coffey CW, DeWerd LA, et al. Report of Task Group 61: AAPM protocol for 40-300 kV x-ray beam dosimetry in radiotherapy and radiobiology. *Med Phys.* 2001;28:868–893. Available from: <http://dx.doi.org/10.1118/1.1374247>
- Mayles WPM, Lake R, McKenzie A, et al., editor. *Physics Aspects of Quality Control in Radiotherapy IPEM Report 81*. York, England: Institute of Physics and Engineering in Medicine; 1999. ISBN 0-904181-91-X.
- Ministry of Health. X-ray equipment in medical diagnosis. Part A: recommended safety procedures for installation and use, safety code 20A. Health Environments and Consumer Safety Branch, Ministry of Public Works and Government Services, Canada; 2000. Available from: http://www.hc-sc.gc.ca/ewh-semt/pubs/radiation/safety-code_20-secure/index-eng.php
- National Council on Radiation Protection and Measurements. *Structural Shielding Design and Evaluation for Medical use of x Rays and Gamma Rays of Energies up to 10 MeV*, Report no. 49. Washington (DC): NCRP; 1976. ISBN 978-0913392316.
- National Council on Radiation Protection and Measurements. *Dosimetry of x ray and Gamma-ray Beams for Radiation Therapy in the Energy Range 10 keV to 50 MeV*, report no. 69. Washington (DC): NCRP; 1981. ISBN 978-0913392553.
- National Council on Radiation Protection and Measurements. Operational radiation safety program, report no. 127. Washington (DC); 1998. ISBN 978-0929600598.
- Nikolic M, Van DJ. Use of a megavoltage constancy meter for orthovoltage quality assurance. *Med Phys.* 1993;20:1747–1750. Available from: <http://dx.doi.org/10.1118/1.596962>
- Government of Canada. Radiation emitting devices regulations, C.R.C., c. 1370. [cited 2016 Jun 07]. Minister of Justice; 2001. Available from: http://laws-lois.justice.gc.ca/PDF/C.R.C.,_c._1370.pdf
- Roessler CE, editor. *Management and Administration of Radiation Safety Programs: Health Physics Society 1998 Summer School*. Madison (WI): Medical Physics Publishing; 1998. ISBN 978-0944838853.
- Videla N, Gillies BA. *Ontario Standards for Quality Assurance: Cobalt-60 Teletherapy Units*. Toronto (ON): Cancer Care Ontario; 1998.
- World Health Organization. *Quality Assurance in Radiotherapy*. Geneva, Switzerland: WHO; 1988. ISBN 978-9241542241.
- Goharian M, Nygren I, Tambasco M, Villarreal-Barajas JE. Angular dependence of the output of a kilovoltage x-ray therapy unit. *J Appl Clin Med Phys.* 2010;11:276–284.