

Canadian Partnership for Quality Radiotherapy

Technical Quality Control Guidelines for Canadian Radiation Treatment Centres

Major Dosimetry Equipment

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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CPQR

Canadian Partnership for
Quality Radiotherapy

PCQR

Partenariat canadien pour
la qualité en radiothérapie

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Preface

The Canadian Partnership for Quality Radiotherapy (CPQR) is an alliance among the 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), together with the Canadian Partnership Against Cancer (CPAC). 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, entitled *“Technical Quality Control Guidelines for Canadian Radiation Treatment Programs – Major Dosimetry Equipment”* is one in a suite of quality control documents that outline specific performance objectives and criteria that equipment should meet in order to assure an acceptable level of radiation treatment quality. This suite of documents has been derived from a previous set of standards prepared by the Canadian Association of Provincial Cancer Agencies (CAPCA) commonly known as the CAPCA Standards (Dunscombe et al., 2007). These guidelines supersede those standards and are intended to provide guidance for the safe and consistent use of equipment and technologies associated with radiation treatment. These guidelines are not intended to set a minimum standard that shall be met within each radiation treatment facility, nor are they intended to be a required component of a site certification program. The *“Technical Quality Control Guidelines”* are created by expert Medical Physicists drawing on current and state-of-the-art testing and performance guidelines and standards. Expert reviewers work in coordination with COMP’s Quality Assurance and Radiation Safety Advisory Committee (QARSAC) on the technical components of the document which is subsequently endorsed by COMP and ratified by CPQR. Radiation safety activities employed at radiation treatment facilities are detailed in CPQR’s companion guidance document *“Quality Assurance Guidelines for Canadian Radiation Treatment Programs.”* The intent of that document is to outline a benchmark for achievement in the areas of quality and safety and to outline key quality indicators for programmatic assessment. The document reflects a consensus view of state-of-the art knowledge in radiation treatment quality and safety. That CPQR companion guidance document, along with the *“Technical Quality Control Guidelines”* suite of documents, and the *“Incident Management Guidance for Canadian Radiation Treatment Programs”* (the latter currently being developed), are living documents that are reviewed and revised at regular intervals by CPQR to maintain relevance in the Canadian radiation treatment environment.

Ownership of CPQR documents resides jointly with the national professional organizations involved in the delivery of radiation treatment in Canada – CARO, COMP, CAMRT, and CPAC. While administration of the *“Technical Quality Control”* suite of guidelines is the responsibility of CPQR, decisions regarding content changes reside with COMP and are made in close partnership with the CPQR Steering Committee and partners.

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All enquiries regarding CPQR documents, including requests for clarification, should be addressed to The Canadian Partnership for Quality Radiotherapy, c/o EDG Consulting, 68 Ironstone Drive, Red Deer Alberta, T4R 0C1. All inquiries will be reviewed by the CPQR Steering Committee.

Requests for interpretation should:

- State the question or problem, making reference to the specific clause in the document;
- Provide an explanation of any specific circumstances relevant to the request; and
- Be phrased where possible to permit a specific “yes” or “no” answer.

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Abbreviations and Definitions

Abbreviations	
AAPM	American Association of Physicists in Medicine
CAMRT	Canadian Association of Medical Radiation Technologists
CAPCA	Canadian Association of Provincial Cancer Agencies
CARO	Canadian Association of Radiation Oncology
CCPM	Canadian College of Physicists in Medicine
COMP	Canadian Organization of Medical Physicists
CNSC	Canadian Nuclear Safety Commission
CPAC	Canadian Partnership Against Cancer
CPQR	Canadian Partnership for Quality Radiotherapy
IPEM	Institute of Physics and Engineering in Medicine
NIST	National Institute of Standards and Technology
NRCC	National Research Council of Canada
QARSAC	Quality Assurance and Radiation Safety Advisory Committee
Definitions	
Expert Reviewer	Medical Physicist charged with the development of the technical tests and performance objectives for the equipment or technology outlined in the specific guideline document.
Organization	The hospital, cancer centre, or institution in which the radiation treatment program resides.
Radiation Treatment Facility	The physical location where radiation treatment is administered.
Radiation Treatment Program	The personnel, equipment, information systems, policies and procedures, and activities required for the safe delivery of radiation treatment according to evidence-based and/or best practice guidelines.
Supervising Physicist	A qualified Medical Physicist, the supervising physicist is responsible for ensuring compliance with the local quality control protocol, maintaining appropriate documentation, taking appropriate remedial actions, and communicating with other members of the radiation therapy team concerning the operational state of the equipment.

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Qualified Medical Physicist	A Medical Physicist who is certified in radiation oncology physics by the Canadian College of Physicists in Medicine or who holds equivalent certification.
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1. Introduction

Approximately 50 % of all incident cases of cancer require radiation treatment at some point during the management of the disease (Delaney et al., 2005). In Canada, in 2012, it is estimated there were approximately 186,400 new cases of cancer (Canadian Cancer Society, 2012) and almost 100,000 courses of radiation treatment were administered (data from the CARO annual workload survey of Canadian radiation treatment programs). There are currently more than 35 radiation treatment facilities in Canada. In all provinces and territories, cancer treatment is funded by the provincial or territorial governments. Radiation treatment equipment is either licensed by the Canadian Nuclear Safety Commission (CNSC) or registered by the appropriate provincial authority, depending on energy and other criteria. Some forms of radiation treatment are administered outside of cancer treatment facilities. Examples include the use of unsealed radiation sources in nuclear medicine departments, or radiation treatment for benign indications in surgical suites or specialized interventional programs. This document applies to a specific piece of equipment or technology employed within a radiation treatment facility.

This document is intended to outline specific performance objectives and safety criteria that the equipment or technology should meet in order to assure an acceptable level of treatment quality. This document also outlines the frequency with which the recommended tests should be carried out. It does not recommend how the specific tests should be carried out. It is the responsibility of the supervising physicist to ensure that locally available test equipment and procedures are sufficiently sensitive to establish compliance with the criteria specified within this document. Taken as a component of the CPQR suite of guidance documents which includes *“Quality Assurance Guidelines for Canadian Radiation Treatment Programs”* and *“Incident Management Guidance for Canadian Radiation Treatment Programs”* (the latter currently being developed), these guidelines are not intended to replace detailed specifications, standard operating procedures or centre-based policies, but rather to support equipment safety measures within the development and maintenance of a national strategy for radiation treatment quality assurance. The ultimate objective of these documents is to assure the highest quality radiation treatment for all Canadians as an integrated element of overall cancer care, and minimize the risk of medical errors and untoward clinical outcomes. Responsibility for implementation of quality assurance programs and monitoring of quality indicators should be taken at the highest operational levels of all cancer treatment organizations and provincial cancer agencies.

2. Performance Objectives and Criteria

Objectives and criteria for the evaluation of the performance of radiation treatment equipment and technologies fall into several categories:

- **Functionality** – Equipment systems and sub-systems for which the criteria of performance are “functional” are either working correctly or not. Such systems are commonly associated with the

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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.

- **Reproducibility** – The results of routine quality control tests, for which reproducibility is the criterion, are assessed against the baseline results obtained from the unit during acceptance testing and/or commissioning. Tolerances and action levels should be set for parameters that can be quantified.
- **Accuracy** – Quality control tests which measure accuracy are designed to assess the deviance of a measured parameter from its expected or defined value. An example would be a test quantifying template positional accuracy.
- **Characterization and documentation** – In some cases it is necessary to take 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 of an ionisation chamber.
- **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 should be defined.

- **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 in relation to that performance parameter.
- **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 that meets all tolerance levels. If this is not immediately possible, then the use of the equipment shall 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 (as outlined in the specific testing criteria). A decision should 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. This decision should be made by the supervising physicist in consultation with the users of the equipment and others as appropriate.

Documentation of equipment performance is important and is discussed in this document. 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 levels then a verbal update is sufficient, however if one or more of the parameters fails to meet the action level criteria defined in this document, and

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immediate action is not possible, then the users of the equipment shall be informed in writing of the conditions under which the equipment should be used. Compliance with action levels but failure to meet described tolerance levels for one or more parameters should 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.

3. System Description

3.1. Ionization chambers and electrometers used for reference dosimetry

The absorbed dose to water at the reference point under reference conditions as specified in the appropriate dosimetry protocols (e.g. AAPM TG-51 (Almond et al., 1999); AAPM TG-61 (Ma et al., 2001); IAEA TRS-398 (IAEA, 2001)) is determined through the use of a chamber/electrometer combination. Local or secondary standards are chamber/electrometer combinations which have a calibration coefficient in terms of absorbed dose directly traceable to a Primary Standards Dosimetry Laboratory (e.g. National Research Council of Canada (NRCC); National Institute of Standards and Technology (NIST); or an Accredited Dosimetry Calibration Laboratory (ADCL)). Redundancy for these devices is recommended to assure the maintenance of the calibration during, and following, calibration at the standards lab (AAPM TG-51 (Almond, 1999); AAPM TG-61 (Ma, 2001); IAEA TRS-398 (IAEA, 2000)). These standards, which comprise a unique chamber/electrometer combination, are the basis of accurate dose delivery and are generally removed from routine clinical use. Routine dose measurements and therapy device calibration in the clinical setting are typically performed with field grade chambers and electrometers (hereafter referred to as field standard) which have a calibration coefficient transferred from the secondary standard.

3.2. Detectors for non-reference dosimetry

These are detectors used to measure dose from a radiation source as a method of ensuring the stability of the device on a routine basis. They can also be used to determine the absolute dose in a phantom or received by a patient following a cross-calibration process. Some of these devices in use include ionization chambers, diodes, Thermoluminescent Dosimeters (TLD), Metal-Oxide Semiconductor Field-Effect Transistors (MOSFETs), Optically Stimulated Luminescence (OSL) systems, radiographic films (AAPM TG-69 (Pai et al., 2007)), and radiochromic films (AAPM TG-55 (Niroomand-Rad et al., 1998)). Both types of films are integral parts of routine quality assurance for Intensity-Modulated Radiation Therapy (IMRT) treatment plans and for stereotactic radiosurgery.

3.3. Basic measurement devices

Most secondary and field standards are vented ionization chambers and as such, are subject to local atmospheric conditions. Therefore thermometers, barometers and hygrometers will be used during reference dosimetry measurements. Basic distance checks will be achieved with a quality ruler or calliper. A quality stopwatch will be used for accurate time measurement. Spirit levels (with or without digital angle display) could be used for levelling scanning water tanks and other measurement phantoms or devices. A self-adjusting laser system projecting two perpendicular laser lines may be used to check the horizontality and verticality of room lasers.

3.4. Automated beam scanning devices

Automatic remotely controlled water scanners comprise a water tank, and a mechanism for holding and moving a radiation detector through the beam. They range in sophistication from ion chamber motion/measurements along a single vertical axis (1D water tanks) to a motion along two (2D water tank) and three directions (3D water tanks). While 1D water tanks are mainly used for chamber positioning at a desired reference point for clinical reference dosimetry (AAPM TG-51 (Almond et al., 1999); AAPM TG-61 (Ma et al., 2001); IAEA TRS-398 (IAEA, 2001)), 3D water tanks are used for beam data acquisition in acceptance testing and commissioning of radiation therapy units, as well as for periodic checks of beam parameters such as flatness, symmetry, depth dose, off-axis ratios, and energy. These systems may also be capable of real-time isodose tracking and dynamic beam measurement, and are equipped with software tools for plotting, analyzing and applying various transformations (shifts, scale, move, smooth, etc.) on measured data, and for converting the ionization depth curves into dose according to various protocols (AAPM TG-51 (Almond et al., 1999); AAPM TG 70 (Gerbi et al., 2009)). Also available are smaller 3D scanning water tanks that fit into the gantry bore of tomotherapy units or that are adapted specifically for Tissue Phantom Ratio (TPR) type measurements of stereotactic fields; these are subject to the same quality control tests as larger scanning water tanks.

3.5. Machine quality assurance devices

Megavoltage beam parameters such as output, field size, flatness, symmetry, beam energy, and constancy can be measured on a routine basis with a variety of devices which are more convenient to use than the water scanner. These devices may consist of one or more two-dimensional detector arrays of diodes or ionization chambers and may have software for processing, analysing, and tracking measured data. These devices, which consist essentially of two dimensional detector arrays, are easy to set-up and use, and their multi-detector construction involving ion chamber and/or diodes makes them useful in the monitoring of technologies such as dynamic wedge and IMRT beam quality assurance (AAPM TG-119 (Ezzell et al., 2009); AAPM TG-120 (Low et al., 2011)).

3.6. Treatment delivery quality assurance devices

The standard of care for patients treated with static or rotational IMRT techniques involves a verification that the beam is delivered accurately and precisely with respect to the treatment. In general, a phantom approach is used, whereby the treatment plan is transferred onto a phantom containing detectors, the dose is re-calculated on the Treatment Planning System (TPS) for this phantom setup and the treatment plan is delivered on the phantom and measured for comparison with the TPS-calculated dose. Various devices available for this pre-treatment Delivery Quality Assurance (DQA) consist of 2D or 3D arrays of diodes or ionization chamber, and have additional hardware and software for instant readout, data manipulation, and analysis of measured dose vs the planned dose. In addition, some 2D arrays have features that can be used for machine quality assurance and also have accessories for mounting them on the linac gantry.

3.7. Phantom Materials

Whereas water is the reference phantom material for clinical reference dosimetry, solid phantoms are typically used for routine measurement. These devices may have radiation absorption properties and interaction coefficients similar to water, and may also be available in other materials such as acrylic, bone, lung, or muscle. The phantom may have “slab” geometry or be anthropomorphic. Anthropomorphic or “humanoid” phantoms are often constructed so as to accommodate TLD, MOSFETs, and film measurements. Motion phantoms that incorporate various forms of detector or target movements are also available for assessing 4D imaging and treatment gating capabilities.

4. Acceptance Testing and Commissioning

Most major dosimetry equipment requires little commissioning and acceptance testing. The exception to this is the automated beam scanning device which, when newly acquired, or when substantially upgraded, requires acceptance testing and commissioning before being put into clinical service.

Acceptance testing and commissioning has several purposes:

- Ensure that the stated specifications or equipment and performance are achievable;
- To obtain all data necessary to put the product or machine into clinical service;
- Establish baseline parameters for a future quality assurance program; and
- Familiarize the customer with the operation of the unit.

Guidelines for acceptance testing of the equipment or technology described in this document should be consistent with routine quality control objectives and criteria. In particular, there is no reason why a new or upgraded system, and its associated safety systems, should not meet the tolerance levels described in this document (see Tables 1 through 7). Tests on all functional systems and sub-systems of

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the described equipment or technology shall be included. These tests should be performed by, or under the supervision of, a qualified Medical Physicist.

Adherence to the guidelines established in Table 1 shall be demonstrated and documented, in or outside of the vendor's acceptance testing protocol, and prior to the equipment or technology being put into clinical service. Also, an appropriate subset of acceptance tests shall be performed after any repair or preventive maintenance interventions on the equipment. The extent of testing required shall 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 operating/performance calculations, for example, involving radiation dose; and
- To establish baseline parameters for the future quality control program.

It is essential that all of the tests listed in Tables 1 through 7 be performed at commissioning with the intended local test equipment and protocols so that meaningful baseline values are established for quality control. All commissioning data should be independently double checked and, where appropriate, an external dosimetry audit performed.

5. Quality Control of Equipment

The purpose of a quality control program is to assure that operational standards for a unit 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.

Tests shall 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 shall independently verify the implementation, analysis, and interpretation of the quality control tests at least annually. This independent check shall be documented.

Daily tests shall be scheduled prior to patient treatments. For other tests, testing at less than the minimum frequency is recommended only if experience has established that the parameters of interest are highly stable. Documentary evidence supporting this decision is essential.

In the event that the equipment does not meet the stated performance objectives and criteria, an adjustment or repair is needed. If it is not possible to restore the equipment to full performance immediately, then the use of the equipment shall be restricted to clinical situations in which the identified inadequate performance is of no, or acceptable and understood, clinical significance. The

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decision of the most appropriate response shall be made by the supervising Medical Physicist in conjunction with the users of the equipment and others as appropriate.

Preventive maintenance schedules and interventions recommended by the manufacturer of the equipment shall be adhered to. Frequently, equipment repairs and quality control testing are performed by different individuals. In such cases, good communication and reporting between the various staff involved is essential.

Radiation safety activities, such as those outlined in CPQR's "*Quality Assurance Guidelines for Canadian Radiation Treatment Centres*" shall be integrated into routine quality control programs for equipment.

The standards for dosimetry equipment quality control are listed in Tables 1 through 7. These minimum standards consist of tests to be performed, along with their minimum frequencies and specified tolerances and action levels. The tests are derived from the published literature, the manufacturers user manuals and recommendations and, in particular, the standards laid out in the American Association of Physicists in Medicine (AAPM) documents (AAPM TG-40 (Kutcher et al., 1994); AAPM TG-142 (Klein et al., 2009); AAPM TG-51 (Almond et al., 1999); AAPM TG-69 (Pai et al., 2007)) and the Institute of Physics and Engineering in Medicine (IPEM) document, Report 81 (IPEM, 1999). Where a tolerance level is specified, it is typically set at 50-75 % of the action level. Given that this report deals with many pieces of equipment that have unique responses that often change with time and that cannot be simply recalibrated, it is often not obvious to set a tolerance and an action level, and hence the frequent use of "characterize and document" in Tables 1 through 7.

An inspection of the frequency table indicates that the majority of tests are to be done at initial receipt of the equipment, or following malfunction and repair, thus they are not expected to lead to an undue increase in the workload for a medical physics department. With the exception of automated beam scanning devices, there were few specific commissioning tests required for major dosimetry equipment. However the tests listed as part of the on-going quality assurance program may also be used as a guide for tests to be carried out upon receipt of new equipment.

Several tests described here may have a critical impact upon the quality of radiation therapy given to patients, and as such should only be carried out by, or under supervision of, a qualified Medical Physicist. Of primary importance is the maintenance of the secondary standard and its standards lab traceable calibration coefficient. Next is the transfer and maintenance of calibration factors to field grade ion chambers and detector arrays used routinely in the clinic. Finally the assessment of energy determining devices and software related to the calculation of photon and electron beam parameters is also critical.

6. Documentation

Appropriate documentation is a required component of a quality control program. All documents associated with the program should contain the following information:

- The name of the institution;
- The name of the originating department;
- The name(s) of the document author(s);
- The name of the individual(s) or group(s) who approved the document for clinical use;
- The date of first issue; and
- The number and date of the current revision.

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

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

The quality control protocol contains the guidelines, performance objectives and criteria, to be applied to a piece of equipment. Guidelines shall be based on the CPQR *“Technical Quality Control Guidelines”* suite of documents such as this one. The protocol should provide sufficient detail concerning the test equipment and procedures to be followed so that there is no 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, a means of documenting any corrective action that takes place is required, together with the results of any subsequent tests. Deviations from the locally approved protocol, such as those resulting from clinical pressure to access the equipment shall be documented as well.

All documentation related to the quality control program must be retained for at least 10 years.

7. Quality Control Tests – Major Dosimetry Equipments

The following Tables list quality control tests, the performance evaluation criteria, and characterization and documentation of major dosimetry equipment. Short description notes are added at the end of the table for each test.

Table 1

Secondary Standard (Chamber and electrometer combination)			
Designator	Test	Performance	
		Tolerance	Action
Initial use and following calibration			
ISS1	Extra -cameral signal (stem effect)	0.5 %	1.0 %
ISS2	Ion collection efficiency	Characterize and document	
ISS3	Polarity correction	Characterize and document	
ISS4	Linearity	0.5 %	1.0 %
ISS5	Leakage	0.1 %	0.2 %
ISS6	Collection potential reproducibility	1.0 %	2.0 %
At each use			
ESS1	Signal reproducibility	0.2 %	0.5 %
Bi-annual (i.e. every two years)			
BSS1	Calibration at standards lab	Every two years	
Field Standard (chamber and electrometer combination)			
Initial use or following malfunction and repair			
IFS1	Extra-cameral signal (stem effect)	0.5 %	1.0 %
IFS2	Ion collection efficiency	Characterize and document	
IFS3	Linearity	0.5 %	1.0 %
IFS4	Leakage	0.1 %	0.2 %
IFS5	Collection potential reproducibility	1.0 %	2.0 %
IFS6	Cross calibration	Characterize and document	
Annual			
AFS1	Signal reproducibility	0.2 %	0.5 %
AFS2	Collection potential reproducibility	1.0 %	2.0 %
AFS3	Cross calibration	Characterize and document	

Notes on Table 1

ISS1 to ISS6 Tolerances based on AAPM TG-40 (Kutcher et al., 1994). Action levels are suggested and may be modified based on experience. Suggested methods for measurement of ion collection efficiency and polarity correction may be found in AAPM TG-51 (Almond et al., 1999). Since collection potential (voltage) is difficult to accurately measure with chamber connected, the user may rely on the internal device readout for the measurement of the collection potential reproducibility test (ISS6).

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ESS1	Based on AAPM TG-40 (Kutcher et al., 1994).
BSS1	Based on AAPM TG-40 (Kutcher et al., 1994).
IFS1 to IFS5	Tolerances based on AAPM TG-40 (Kutcher et al., 1994). Action levels are suggested and may be modified based on experience. Suggested methods for measurement may be found in AAPM TG-51 (Almond et al., 1999).
IFS6	Based on clinical experience.
AFS1, AFS2	Based on clinical experience and AAPM TG-40 (Kutcher et al., 1994). Since collection potential (voltage) is difficult to accurately measure with chamber connected, the user may rely on the internal device readout for the measurement of the collection potential reproducibility test (ISS6).
AFS3	Modified frequency from AAPM TG-40 (Kutcher et al., 1994) based on clinical experience.

Table 2

Detectors for non-reference dosimetry			
Designator	Test	Performance	
		Tolerance	Action
Thermoluminescent dosimeter (TLD) systems			
Initial use or following malfunction and repair			
IRD1	Linearity or supralinearity	Characterize and document	
At each use			
ERD1	Individual absolute dose cross-calibration	Characterize and document	
Radiographic and radiochromic film dosimetry systems			
Initial use or following malfunction and repair			
IRD2	Sensitometric curve	Characterize and document	
IRD3	Dose response curve	Characterize and document	
IRD4	Film reader linearity and reproducibility	Characterize and document	
IRD5	Film processor acceptance tests	See AAPM TG-69 (Pai et al., 2007)	
Annual			
ARD1	Film reader linearity and reproducibility	Characterize and document	
Ionization chambers for relative dosimetry			
Initial use or following malfunction and repair			
IRD6	Linearity (dose and dose rate)	0.5 %	1.0 %
IRD7	Extra-cameral signal (stem effect)	0.5 %	1.0 %
Annual			
ARD2	Signal reproducibility	0.5 %	1.0 %
Diode systems			
Initial use or following malfunction and repair			
IRD8	Linearity	Characterize and document	

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IRD9	Energy dependence	Characterize and document
Annual or shorter (depending on workload)		
ARD3	Absolute dose calibration (if required)	Characterize and document
MOSFETs		
Initial use or following malfunction and repair		
IRD10	Energy dependence	Characterize and document
IRD11	Absolute dose calibration	Characterize and document
Annual or shorter (depending on workload)		
ARD4	Absolute dose calibration	Characterize and document
Optically Stimulated Luminescence (OSL) systems		
Initial use or following malfunction and repair		
IRD12	Linearity	Characterize and document
IRD13	Absolute dose calibration	Characterize and document
Annual or shorter (depending on workload)		
ARD5	Absolute dose calibration	Characterize and document

Notes on Table 2

IRD1	Based on AAPM TG-40 (Kutcher et al., 1994). Investigation of linearity and supralinearity for a sample of a few TLDs from a batch.
ERD1	Based on AAPM TG-40 (Kutcher et al., 1994). Multiple TLDs can be cross-calibrated simultaneously against an ion chamber measured dose at a reference depth in a solid phantom using a uniform radiation field.
IRD2 to IRD4	Can be established using classic H&D curve for one film for each new batch. Effects of batch film changes should be routinely assessed. Various techniques for obtaining a sensitometric and a dose response curve are described in AAPM TG-69 (Pai et al., 2007) for radiographic films and in AAPM TG-55 (Niroomand-Rad et al., 1998) for radiochromic films.
IRD5	Acceptance tests based on AAPM TG-69 (Pai et al., 2007) and manufacturer recommendations. If radiographic films are used for absolute dosimetry, one should consider additional routine tests recommended in Table II of AAPM TG-69 (Pai et al., 2007) to ensure the stability of film processing. This item is not applicable to radiochromic films since they do not require any post irradiation processing.
ARD1	Based on AAPM TG-40 (Kutcher et al., 1994).
IRD6, IRD7, ARD2	Based loosely on AAPM TG-40 (Kutcher et al., 1994) and clinical experience.
IRD8 to IRD9	Based on AAPM TG-40 (Kutcher et al., 1994).
ARD3	Based on AAPM TG-40 (Kutcher et al., 1994). Absolute dose calibration to be done if required.

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- IRD10, IRD11 Energy dependence of MOSFETs can be addressed by performing an absolute dose cross-calibration in the beam energy and conditions they are intended to be used. Cross-calibration for each beam quality against an ion chamber dose (as per AAPM TG-51 (Almond et al., 1999) or TG-43 (Nath et al., 1995)) following manufacturers’ recommendations.
- ARD4 Absolute dose cross-calibration in the beam energy and under conditions they are intended to be used.
- IRD12 Linearity of the OSLs should be checked prior to use in order to assess the dose range at which the dosimeter remains linear.
- IRD13, ARD5 Commercially available OSLs show minimal energy dependence in the megavoltage clinical energy range 6-25 MeV. Substantial energy dependence has been found in the kV range. Therefore the same absolute calibration factor can be used in the megavoltage energy range, while an energy-dependent calibration should be done for energies in the kV range.

Table 3

Basic measurement devices			
Designator	Test	Performance	
		Tolerance	Action
Reference thermometer, Barometer, Hygrometer			
Initial use or following malfunction and repair			
IBM1	Calibration certificate	Characterize and document	
Annual			
ABM1	Absolute calibration	Characterize and document	
Field thermometer, Barometer, Hygrometer			
Initial use or following malfunction and repair			
IBM2	Cross calibration	Characterize and document	
Annual			
ABM2	Cross calibration	Characterize and document	
Spirit levels, self-levelling laser system			
Initial use or following malfunction and repair			
IBM3	Calibration check	Characterize and document	
At each use			
EBM3	Calibration check	Characterize and document	

Notes on Table 3

- IBM1 Certificates are retained for reference devices.
- ABM1 Calibration of reference devices to absolute values every year.
- IBM2, ABM2 Field devices are compared (cross-calibrated) against reference devices prior to initial use and every year except for barometers (6 months). Field devices are also checked against each other to identify damage. Frequency for

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barometers changed from 3 months (see AAPM TG-40 (Kutcher et al., 1994)) to 6 months based on local experience. Comparison of local barometer readings against the local airport system (corrected for altitude difference) is recommended. Digital barometers often require a correction factor that converts the digital readout into the true pressure. Barometers (analog and digital) are checked every 3 months (see AAPM TG-40 (Kutcher et al., 1994)).

IBM3, EBM3

Based on manufacturers' recommendations. Certificates are retained for documentation. For a spirit level, its reading when placed on a flat or vertical surface should be the same when it is 180° rotated along an axis perpendicular to the surface. The verticality and horizontality of the lines projected by the self levelling laser should also be checked at each use.

Table 4

Automated (1D, 2D and 3D) beam scanning devices and detector arrays			
Designator	Test	Performance	
		Tolerance	Action
Mechanical components			
Initial use or following malfunction and repair			
IBS1	Alignment	Characterize and document	
IBS2	Hysteresis	Characterize and document	
IBS3	Orthogonality/Verticality	Characterize and document	
Annual			
ABS1	Positional Accuracy	1 mm	2 mm
Detectors (ion chambers and diodes)			
Initial use or following malfunction and repair			
IBS4	Extracameral signal (stem effect)	0.5 %	1.0 %
IBS5	Linearity	0.5 %	1.0 %
IBS6	Leakage	0.5 %	1.0 %
Annual			
ABS2	Reproducibility of collection potential	0.5 %	1.0 %
Data acquisition/Analysis			
Initial use or following malfunction, repair or software upgrade			
IBS7	Scan speed insensitivity	Characterize and document	
IBS8	Scan mode (continuous vs step-by-step) insensitivity	Characterize and document	
IBS9	Agreement with static measurements	1.0 %	2.0 %
IBS10	Symmetry/Flatness calculations	1.0 %	2.0 %
IBS11	Energy/Bremsstrahlung calculations	1.0 %	2.0 %
IBS12	Ionization-to-dose calculations	1.0 %	2.0 %
IBS13	Accuracy of output (Distance To Agreement (DTA))	1.0 mm	2.0 mm

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Notes on Table 4

IBS1 to IBS3	Based on clinical experience. Tolerances on the order of 0.5 mm are probably acceptable. Acceptance test criteria may be provided by the vendor as a guideline. A typical hysteresis check is to ensure that scanning in opposite directions leads to the same output.
ABS1	Based on clinical experience. Users may adapt and document criterion to local needs. Stated specifications from all current manufacturers are smaller than 0.5 mm.
IBS4	Based on IFS1.
IBS5	Based on similar criteria for IFS3.
IBS6	Based on IFS4 with looser criteria.
ABS2	Based on similar criteria for IFS5.
IBS7 to IBS13	Tests based on clinical experience and may be modified to meet the user criteria. Tests may also be modified to follow the vendor's acceptance test criteria.

Table 5

Machine quality assurance devices			
Diode and ionization chamber Arrays			
Designator	Test	Performance	
		Tolerance	Action
Initial use or following malfunction and repair			
IMQ1	Accuracy (DTA)	1.0 mm	2.0 mm
IMQ2	Signal reproducibility	Characterize and document	
IMQ3	Linearity (dose and dose-rate)	Characterize and document	
IMQ4	Agreement with static measurements	1.0 %	2.0 %
IMQ5	Symmetry and flatness calculations	1.0 %	2.0 %
IMQ6	Energy dependence	Characterize and document	
Annual or bi-annual (i.e. every 2 years)			
AMQ1	Relative array calibration	Characterize and document	

Notes on Table 5

IMQ1 to IMQ5	Based loosely on IBS5 to IBS11 and AAPM TG-40 (Kutcher et al., 1994). In addition, the manufacturers' acceptance test procedures may be used to modify the users' criteria.
IMQ6	Based on clinical experience and manufacturers recommendations. If devices are used across a range of beam energies, care must be taken to investigate

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their energy dependence and ensure that the appropriate calibration factors are applied for each measurement.

AMQ1 Based on clinical experience and manufacturers recommendations. Array calibration ensures that all detectors in the array have the same sensitivity and thus eliminates response differences between individual detectors of the array. The resulting calibration factors may be energy-dependent. Array calibration procedures and protocols are device-specific and are provided by all vendors. Recalibration intervals depend on the type of detectors in the array (ion chamber or diode) and on the clinical workload. Vendor’s guideline for array recalibration intervals can be followed.

Table 6

Treatment delivery quality assurance devices			
Gantry Mounting Accessories			
Designator	Test	Performance	
		Tolerance	Action
Initial use or following malfunction and repair			
ITQ1	Gantry mount	Functional	
ITQ2	Alignment of detector CAX with cross-hair	Characterize and document	
ITQ3	Detector plane position relative to the isocentre	Characterize and document	
Inclinometers			
Initial use or following malfunction and repair			
ITQ4	Inclinometer angle accuracy	0.5°	1.0°
Diode and ionization chamber arrays (2D and 3D)			
Initial use or following malfunction and repair			
ITQ5	Signal reproducibility	Characterize and document	
ITQ6	Linearity (dose and dose rate)	Characterize and document	
ITQ7	Agreement with static measurements (%/DTA)	1.0 %/1 mm	2.0 %/2 mm
ITQ8	Orientation of measured dose vs TPS dose map	Characterize and document	
ITQ9	Energy dependence	Characterize and document	
Semi annual			
STQ1	Agreement of device measurement with TPS	Analysis parameters: Gamma Index with 3 % dose difference and 3mm DTA. Passing criteria: At least 95 % of detectors with a GI ≤1.	
Annual or bi-annual (i.e. every 2 years)			
ATQ1	Relative array calibration	Characterize and document	
ATQ2	Absolute cross-calibration	1.0 %	2.0 %

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Notes on Table 6

ITQ1	Based on clinical experience and manufacturers recommendations. It should be possible to attach the gantry mount accessory tightly on the gantry and to fix the detector array on it so that the detector does not move as the gantry and/or collimator rotate.
ITQ2, ITQ3	Based on clinical experience. With the detector array fixed on the gantry mount, the central axis of the detector array should align with the Linac Cross-hair and the detector plane should be at isocentre. A 2 mm tolerance could be used here. Gross errors in the alignment and positioning can be corrected by adjusting the phantom setup in the TPS or by manipulation of device-measurements. Also applies to relevant beam quality assurance devices.
ITQ4	Based on gantry/collimator angle indicators tolerance from AAPM TG-40 (Kutcher et al., 1994) and AAPM TG-142 (Klein et al., 2009).
ITQ5, ITQ6	Based on AAPM TG-40 (Kutcher et al., 1994). Manufacturers' specifications can be used to set device-specific tolerance and action levels.
ITQ7	Tolerances based on AAPM TG-40 (Kutcher et al., 1994) and review of manufacturers' specifications.
ITQ8	For each TPS, care must be taken to ensure that dose import parameters are setup correctly for TPS coordinates to match those of the measuring device.
ITQ9	Same as IMQ6.
STQ1	This is a consistency check based on clinical experience: a static field and an IMRT DQA plan can be created on the CT data set of the device in the treatment planning system. These plans are periodically delivered on the device for consistency checks and analyzed with the Gamma Index parameters indicated. For the case of a static field, tighter tolerances can be used. However, the passing criteria can be adjusted locally based on the accuracy of the beam model of the TPS.
ATQ1	Same as AMQ1.
ATQ2	Based on clinical experience. Absolute dose cross-calibration (at each beam quality) must be done following vendor's recommendations and against an ion chamber dose obtained following AAPM TG-51 (Almond et al., 1999), IAEA TRS-398 (IAEA, 2001), or TG-148 (Langen et al., 2010). After transfer of ion chamber dose to the device, the latter can be irradiated with the same beam used for calibration and the dose measured by the reference detector should agree with the ion chamber dose within indicated tolerance levels. This setup can also be used for routine checks of the absolute calibration of the device. Recalibration frequency is suggested by vendors and depends on workload

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for diode arrays. If devices are used across a range of beam energies, care must be taken to ensure that the correct calibration factors are applied.

Table 7

Phantom materials			
Designator	Test	Performance	
		Tolerance	Action
Initial use			
IPM1	Physical density, composition, electron density, homogeneity	Characterize and document	
IPM2	Dimensions of slabs or pieces	Characterize and document	

Notes on Table 7

IPM1 to IPM2 Inspection and radiographic verification prior to use is recommended. The tolerance depends on the intended use of the material and may be appropriately chosen by the user.

Bibliography

- P.R. Almond, P.J. Biggs, B.M. Coursey, W.F. Hanson, M. Saiful Huq, R. Nath, and D.W.O. Rogers, "AAPM's TG-51 protocol for clinical reference dosimetry of high-energy photon and electron beams," *Med. Phys.* **26**, 1847 (1999).
- Canadian Cancer Society, *Canadian Cancer Statistics 2012* (2012).
- J.E. Cygler and P. Scalchi, "MOSFET dosimetry in radiotherapy," in *Clinical Dosimetry Measurements in Radiotherapy*, edited by D.W.O. Rogers and J.E. Cygler (Medical Physics Publishing, Madison, Wisconsin, 2009)
- G. Delaney, S. Jacob, C. Featherstone, and M. Barton, "The role of radiotherapy in cancer treatment: estimating optimal utilization from a review of evidence-based clinical guidelines," *Cancer* **104** (6), 1129-37 (2005).
- P. Dunscombe, C. Aresnault, J.P. Bissonnette, H. Johnson, G. Mawko, and J. Seuntiens, "The development of quality control standards for radiation therapy in Canada," *J. Appl. Clin. Med. Phys.* **8** (1), 108-18 (2007).
- G.A. Ezzell, J.W. Burmeister, N. Dogan, T.J. LoSasso, J.G. Mechalakos, D. Mihailidis, A. Molineu, J.R. Palta, C.R. Ramsey, B.J. Salter, J. Shi, P. Xia, N.J. Yue, and Y. Xiao, "IMRT commissioning: multiple institution planning and dosimetry comparisons, a report from AAPM Task Group 119," *Med. Phys.* **36** (11), 5359-73 (2009).
- B.J. Gerbi, J.A. Antolak, F.C. Deibel, D.S. Followill, M.G. Herman, P.D. Higgins, M.S. Huq, D.N. Mihailidis, E.D. Yorke, K.R. Hogstrom, and F.M. Khan, "Recommendations for clinical electron beam dosimetry: supplement to the recommendations of Task Group 25," *Med Phys.* **36** (7), 3239-79 (2009).
- IAEA (International Atomic Energy Agency), *Absorbed Dose Determination in External Beam Radiotherapy: An International Code of Practice for Dosimetry based on Standards of Absorbed Dose to Water*, Technical Reports Series 398 (2001).
- IPEM (Institute of Physics and Engineering in Medicine), *Physics Aspects of Quality Control in Radiotherapy*, Report No. 81, edited by W.P.M. Moyles et al. (York, England, 1999).
- ISO (International Organization for Standardization), "Model for quality assurance in design, development, production, installation and servicing," ISO 9001:1994 (1994).
- ISO (International Organization for Standardization), "Quality management systems – requirements," ISO 9001:2000 (2000).

Technical Quality Control Guidelines for Canadian Radiation Treatment Centres Major Dosimetry Equipment

- E.E. Klein, J. Hanley, J. Bayouth, F.F. Yin, W. Simon, S. Dresser, C. Serago, F. Aguirre, L. Ma, B. Arjomandy, C. Liu, C. Sandin, and T. Holmes, "Task Group 142 report: quality assurance of medical accelerators," *Med. Phys.* **36** (9), 4197-212 (2009).
- G.J. Kutcher, L. Coia, M. Gillin, W.F. Hanson, S. Leibel, R.J. Morton, J.R. Palta, J.A. Purdy, L.E. Reinstein, G.K. Svensson, et al., "Comprehensive QA for radiation oncology: report of AAPM Radiation Therapy Committee Task Group 40," *Med. Phys.* **21** (4), 581-618 (1994).
- K.M. Langen, N. Papanikolaou, J. Balog, R. Crilly, D. Followill, S.M. Goddu, W. Grant, G. Olivera, C.R. Ramsey, and C. Shi, "QA for helical tomotherapy: report of the AAPM Task Group 148," *Med. Phys.* **37** (9), 4817-53 (2010).
- D.A. Low, J.M. Moran, J.F. Dempsey, L. Dong, and M. Oldham, "Dosimetry tools and techniques for IMRT," *Med. Phys.* **38** (3), 1313-38 (2011).
- C.M. Ma, C.W. Coffey, L.A. DeWerd, C. Liu, R. Nath, S.M. Seltzer, and J.P. Seuntjens, "AAPM protocol for 40-300 kV x-ray beam dosimetry in radiotherapy and radiobiology," *Med. Phys.* **28** (6), 868-93 (2001).
- R. Nath, L.L. Anderson, G. Luxton, K.A. Weaver, J.F. Williamson, and A.S. Meigooni, "Task Group No. 43, Dosimetry of interstitial brachytherapy sources: recommendations of the AAPM Radiation Therapy Committee Task Group No. 43. American Association of Physicists in Medicine," *Med. Phys.* **22** (2), 209-34 (1995).
- A. Niroomand-Rad, C.R. Blackwell, B.M. Coursey, K.P. Gall, J.M. Galvin, W.L. McLaughlin, A.S. Meigooni, R. Nath, J.E. Rodgers, and C.G. Soares, "Radiochromic film dosimetry: recommendations of AAPM Radiation Therapy Committee Task Group 55. American Association of Physicists in Medicine," *Med. Phys.* **25** (11), 2093-115 (1998).
- S. Pai, I.J. Das, J.F. Dempsey, K.L. Lam, T.J. Losasso, A.J. Olch, J.R. Palta, L.E. Reinstein, D. Ritt, and E.E. Wilcox, "TG-69: radiographic film for megavoltage beam dosimetry," *Med. Phys.* **34** (6), 2228-58 (2007).