Development of quality control standards for radiation therapy equipment in Canada

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Received 18 August 2006; accepted 20 September 2006

Among the essential components of a comprehensive quality assurance program in radiotherapy are the quality control protocols to be used on the equipment and, in particular, the performance objectives and criteria. In the present work, we describe the development of a suite of quality control documents for use across Canada. Following a generic format, we are generating concise, clear standards for the most commonly used equipment in radiotherapy, with the emphasis on performance measures. The final standards of performance are confirmed following cross-country consultation facilitated by the availability of draft documents on the Canadian Medical Physics web site.

PACS number: 87.53.Xd

Key words: radiotherapy, quality control, Canada

I. INTRODUCTION

The provision of health care services to Canadians is largely the responsibility of the ten provinces and three territories. Although the services that must be provided free to the population are specified in the federal Canada Health Act, operational and financial aspects of service provision are determined by the provinces and territories. This service delivery structure applies equally to cancer care as it does to other medical services.

The Canadian Association of Provincial Cancer Agencies (CAPCA) is a body that meets regularly to discuss issues of common interest to the organizations responsible for the delivery of cancer care in Canada. A proposal recently accepted by CAPCA was to initiate a process aimed at harmonizing quality assurance activities in radiation treatment programs across the country. This initiative has resulted in a draft document titled Standards for Quality Assurance at Canadian Radiation Treatment Centres. Practical and essential components of any quality assurance program for radiation therapy are the quality control tests carried out on the increasingly sophisticated equipment used in the planning and delivery of treatment. The draft document referred to appendices, which, when developed, would specify the performance standards to be required of equipment used in the preparation and delivery of radiation therapy to all Canadian cancer patients.

The development of the quality control standards themselves was, appropriately, delegated to the national professional body representing Canadian radiation oncology physicists: the Canadian Organization of Medical Physicists (COMP). In turn, COMP established a Task Group,
the members of which are the authors of the present work, to coordinate the generation of the standards documents.

We here describe the philosophy, format, and process adopted by the Task Group, and we refer readers to the web site on which both the approved and draft standards may be reviewed.

II. MATERIALS AND METHODS

A. Documents

The documents upon which the standards are based originated from several sources. Some of the original documents were developed by the Medical Physics Professional Advisory Committee of Cancer Care Ontario and its predecessor, the Ontario Cancer Treatment and Research Foundation. Documents dealing with more recent technology were either specifically commissioned by CAPCA for the purpose of standards development, or, in one case, was based on a recent publication. Also vital to the present project are the many publications relating to quality control and quality assurance in radiotherapy. These include—but are not limited to—recommendations promulgated by the American Association of Physicists in Medicine,\(^1\) The Institute of Physics and Engineering in Medicine,\(^2\) and medical physics compendia.\(^3,4\)

B. Philosophy and scope

The philosophy behind the development of the Standards documents was that they should focus on the standards themselves and not include descriptions of how the tests are performed. It is assumed that physicists who perform or who supervise the performance of the tests possess an appropriate level of knowledge. Otherwise, the bibliography refers the physicist to the recent literature on the subject. Furthermore, radiation safety has not been specifically included. To do so would require updating the documents each time federal or provincial regulations change, and the Task Group did not feel able to accept this responsibility. However, for completeness, some of the more straightforward tests performed on a daily basis were included.

The Standards documents are intended to be brief and unambiguous. Distribution through a web site facilitates updates as experience with new techniques is gained.

To maintain focus and unambiguity, a generic document format was adopted, with these sections:

- Introduction—largely generic
- Performance Objectives and Criteria—generic
- System Description—custom
- Acceptance Tests and Commissioning—largely generic
- Quality Control of Equipment—largely generic
- Documentation—generic
- Table of QC Tests—custom entries in a generic format
- References and Bibliography—custom

C.1 Performance Objectives and Criteria

The generic Performance Objectives and Criteria section includes six classes:

- Functionality
- Reproducibility
- Accuracy
- Characterisation and Documentation
- Data Transfer and Validation
- Completeness
As an example of a generic portion of the documents, Appendix 1 shows the exact wording used in the Performance Objectives and Criteria section. The attempt here, and elsewhere in the generic sections, is to be unambiguous and, where appropriate, prescriptive. The six classes were considered to encompass the range of responses that adequately describe the results of testing. Frequency of testing is also clearly specified, but provides flexibility for operational considerations.

D. Document generation and review

Regardless of whether a source document was commissioned specifically for the development of the Standards or had been generated before this project was initiated, it was sent to a knowledgeable Canadian medical physicist for external review. The reviewer looked at the source document in the light of relevant international recommendations and provided detailed comments on the suggested standards.

Two of the authors of the present work were assigned to each document, one as the primary task group reviewer and one as the secondary reviewer. It was the responsibility of these two members of the group to consider the source document, the external reviewer’s comments, and the international literature; to recommend the draft standards; and then to prepare the relevant documentation in the format described above. This task has been simplified for the more recent documents, because the generic format had been decided, and standards could be commissioned to be consistent with that format.

Once the primary and secondary task group reviewers had agreed on their version of the standard, that standard was circulated to whole Task Group for approval. Following this final internal step, the standard was posted on www.medphys.ca for consideration by the Canadian medical physics community at large.

During the next phase, which is ongoing, the comments from physicists “in the field” are being solicited and considered. Comments are fed back into the internal review process, and the standard is modified if required. Comments received so far have ranged from technical to language to typographical. Once the Task Group has reviewed, incorporated, and approved suggested changes, the standards undergo one final formal review by the Canadian Organization of Medical Physicists before national adoption. So far, the national review process has been completed for the first six standards.

III. RESULTS

At the time of writing, standards documents for the following equipment have been approved by COMP:

- Linear accelerators
- Conventional simulators
- Orthovoltage units
- Cobalt units
- Multileaf collimators
- Electronic portal imaging devices

The following draft standards have been posted and are currently under national review:

- Remote afterloading brachytherapy equipment
- Major dosimetry equipment
- CT simulators
- Prostate brachytherapy equipment
- SRS/T equipment.
Tables 1–6 show the six currently approved standards and illustrate the generic format adopted. Notes (not shown for space reasons) accompany each table to clarify the meaning of numerical tolerances and action levels, but these notes do not recommend measurement techniques.

Standards currently under development include those for:

- Data management systems
- Treatment planning systems
- Intensity-modulated radiation therapy

These latter standards will be posted as they become available. The interested reader is directed to www.medphys.ca to review the complete results of the project to date.

**Table 1.** Quality control tests for medical linear accelerators (tolerances and action levels are specified in millimeters unless otherwise stated)

| Designator | Test                                | Tolerance | Action |
|------------|-------------------------------------|-----------|--------|
| **Daily**  |                                     |           |        |
| DL1        | Door interlock/last person out      | Functional|        |
| DL2        | Motion interlock                    | Functional|        |
| DL3        | Couch brakes                        | Functional|        |
| DL4        | Beam status indicators              | Functional|        |
| DL5        | Patient audiovisual monitors        | Functional|        |
| DL6        | Room radiation monitors             | Functional|        |
| DL7        | Beam interrupt/counters             | Functional|        |
| DL8        | Lasers/crosswires                   | 1         | 2      |
| DL9        | Optical distance indicator          | 1         | 2      |
| DL10       | Optical back pointer                | 2         | 3      |
| DL11       | Field size indicator                | 1         | 2      |
| DL12       | Output constancy—photons            | 2%        | 3%     |
| DL13       | Dynamic wedge factors               | 1%        | 2%     |
| DL14       | Output constancy—electrons          | 2%        | 3%     |
| **Monthly**|                                     |           |        |
| ML1        | Emergency off                       | Functional|        |
| ML2        | Wedge, tray cone interlocks         | Functional|        |
| ML3        | Accessories integrity and centering | Functional|        |
| ML4        | Gantry angle readouts               | 0.5°      | 1°     |
| ML5        | Collimator angle readouts           | 0.5°      | 1°     |
| ML6        | Couch position readouts             | 1         | 2      |
| ML7        | Couch isocenter                     | 1         | 2      |
| ML8        | Couch angle                         | 0.5°      | 1°     |
| ML9        | Optical distance indicator          | 1         | 2      |
| ML10       | Crosswire centering                 | 1         | 2      |
| ML11       | Light/radiation coincidence         | 1         | 2      |
| ML12       | Field size indicator                | 1         | 2      |
| ML13       | Relative dosimetry                  | 1%        | 2%     |
| ML14       | Central axis depth dose reproductibility | 1 (2%)  | 2 (3%)|
| ML15       | Beam flatness                       | 2%        | 3%     |
| ML16       | Beam symmetry                       | 2%        | 3%     |
| ML17       | Records                             | Complete  |        |
| **Annually**|                                     |           |        |
| AL1        | Reference dosimetry—TG51           | 1%        | 2%     |
| AL2        | Relative output factor reproducibility | 1%    | 2%     |
| AL3        | Wedge transmission factor reproducibility | 1%    | 2%     |
| AL4        | Accessory transmission factor reproducibility | 1%    | 2%     |
| AL5        | Output reproducibility vs. gantry angle | 1%    | 2%     |
| AL6        | Beam symmetry reproducibility vs. gantry angle | 2%    | 3%     |
| AL7        | Monitor chamber linearity           | 1%        | 2%     |
| AL8        | End monitor effect                  | 0.1 MU    | 0.2 MU |
| AL9        | Collimator rotation isocenter       | 1         | 2      |
| AL10       | Gantry rotation isocenter           | 1         | 2      |
| AL11       | Couch rotation isocenter            | 1         | 2      |
| AL12       | Coincidence of collimator, gantry, couch axes | 1    | 2      |
| AL13       | Coincidence of isocenters           | 1         | 2      |
| AL14       | Couch deflection                    | 3         | 5      |
| AL15       | Independent quality control review  | Complete  |        |
| Designator | Test | Performance | Tolerance | Action |
|------------|------|-------------|-----------|--------|
| **Daily**  |      |             |           |        |
| DS1        | Door interlock | Functional |           |        |
| DS2        | Motion interlock | Functional |           |        |
| DS3        | Beam status indicators | Functional |           |        |
| DS4        | Emergency off buttons | Functional |           |        |
| DS5        | Collision avoidance | Functional |           |        |
| DS6        | Lasers/crosswires | 1 2 |           |        |
| DS7        | Optical distance indicator | 1 2 |           |        |
| DS8        | Crosswires/reticle/block tray | 1 2 |           |        |
| DS9        | Light/radiation coincidence | 1 2 |           |        |
| DS10       | Field size indicators | 1 2 |           |        |
| **Monthly**|      |             |           |        |
| MS1        | Gantry angle readouts | 0.5° 1° |           |        |
| MS2        | Collimator angle readouts | 0.5° 1° |           |        |
| MS3        | Couch position readouts | 1 2 |           |        |
| MS4        | Alignment of FAD movement | 1 2 |           |        |
| MS5        | Couch isocenter | 2 3 |           |        |
| MS6        | Couch parallelism | 1 2 |           |        |
| MS7        | Laser/crosswire isocentricity | 1 2 |           |        |
| MS8        | Optical distance indicator | 1 2 |           |        |
| MS9        | Crosswire centering | 1 2 |           |        |
| MS10       | Light/radiation coincidence | 1 2 |           |        |
| MS11       | Field size indicators | 1 2 |           |        |
| MS12       | Records | Complete |           |        |
| **Six-monthly**| | | | |
| SS1        | Lead apron | Functional |           |        |
| SS2        | kV | 5% 10% |           |        |
| SS3        | Reference dosimetry | 5% 10% |           |        |
| SS4        | Beam quality (HVL) | 5% 10% |           |        |
| SS5        | Automatic exposure control | 5% 10% |           |        |
| SS6        | Focal spot | Reproducible |           |        |
| SS7        | Contrast | Reproducible |           |        |
| SS8        | Resolution | Reproducible |           |        |
| SS9        | Fluoroscopic timer | 5% 10% |           |        |
| **Annually**| | | | |
| AS1        | Redefine isocenter | 1 2 |           |        |
| AS2        | Couch deflection | 3 5 |           |        |
| AS3        | Alignment of focal spots | 0.5 1 |           |        |
| AS4        | Independent quality control review | Complete |           |        |
TABLE 3. Quality control tests for kilovoltage radiotherapy units (tolerances and action levels are specified in millimeters unless otherwise stated)

| Designator | Test                                                                 | Performance |
|------------|----------------------------------------------------------------------|-------------|
|            | Daily                                                                |             |
| DK1        | Patient monitoring audiovisual devices                             | Functional  |
| DK2        | Door closing mechanism and interlock                               | Functional  |
| DK3        | Couch movement and brakes                                          | Functional  |
| DK4        | Unit motions and motion stops                                      | Functional  |
| DK5        | Interlocks for added filters/kV-filter choice                       | Functional  |
| DK6        | Beam status indicators                                             | Functional  |
| DK7        | Beam-off at key-off test                                           | Functional  |
| DK8        | Emergency off test                                                 | Functional  |
| DK9        | kV and mA indicators                                               | Functional  |
| DK10       | Backup timer/monitor unit channel check                             | 1%          |
| DK11       | Dosimetric test: output check                                      | 3%          |
|            | Monthly                                                              |             |
| MK1        | Mechanical stability and safety                                     | Functional  |
| MK2        | Cone selection and competency                                      | Functional  |
| MK3        | Physical distance indicators                                        | 2           |
| MK4        | Accuracy of head tilt and rotation readouts                         | 1°          |
| MK5        | Light/x-ray field coincidence                                       | 2           |
| MK6        | Light field size                                                   | 2           |
| MK7        | X-ray field size indicator                                          | 2           |
| MK8        | X-ray field uniformity/filter integrity                             | 5%          |
| MK9        | Timer and end effect error                                          | Characterize|
|            | Monthly                                                              | ≥±0.05 min  |
| MK10       | Output linearity                                                    | 1%          |
| MK11       | Output reproducibility                                             | Characterize|
| MK12       | Beam quality                                                       | 10%         |
| MK13       | Output calibration verification                                      | 2%          |
| MK14       | Timer accuracy verification                                          | 2%          |
| MK15       | Records                                                             | Complete    |
|            | Annually                                                             |             |
| AK1        | Reference dosimetry                                                | 1%          |
| AK2        | Alignment of focal spots                                           | 0.5         |
| AK3        | kVp measurement                                                     | 5%          |
| AK4        | Focal spot size                                                     | Reproducible|
| AK5        | Independent quality control review                                  | Complete    |
| Designator | Test Description                                      | Performance Tolerance | Action     |
|------------|--------------------------------------------------------|------------------------|------------|
| **Daily**  |                                                        |                        |            |
| DCO1       | Door interlock/last person out                         | Functional             |            |
| DCO2       | Motion interlock                                       | Functional             |            |
| DCO3       | Couch brakes                                           | Functional             |            |
| DCO4       | Beam status indicators                                 | Functional             |            |
| DCO5       | Patient audiovisual monitors                           | Functional             |            |
| DCO6       | Room radiation monitors                                | Functional             |            |
| DCO7       | Emergency off                                          | Functional             |            |
| DCO8       | Beam interrupt/counters                                | Functional             |            |
| DCO9       | Head swivel lock                                       | Functional             |            |
| DCO10      | Lasers/crosswires                                      | 1                      | 2          |
| DCO11      | Optical distance indicator                             | 1                      | 2          |
| DCO12      | Optical back pointer                                   | 2                      | 3          |
| DCO13      | Field size indicator                                   | 1                      | 2          |
| **Monthly**|                                                        |                        |            |
| MCO1       | Latching of wedges, trays                              | Functional             |            |
| MCO2       | Wedge interlocks                                       | Functional             |            |
| MCO3       | Gantry angle readouts                                  | 0.5°                   | 1°         |
| MCO4       | Collimator angle readouts                              | 0.5°                   | 1°         |
| MCO5       | Couch position readouts                                | 1                      | 2          |
| MCO6       | Couch rotation isocenter                               | 2                      | 3          |
| MCO7       | Optical distance indicator                             | 1                      | 2          |
| MCO8       | Crosswire centering                                    | 1                      | 2          |
| MCO9       | Light/Radiation coincidence                            | 2                      | 3          |
| MCO10      | Field size indicator                                   | 1                      | 2          |
| MCO11      | Relative dosimetry                                     | 1%                     | 2%         |
| MCO12      | Shutter error                                          | Reproducible           |            |
| MCO13      | Beam symmetry (source position)                        | 2%                     | 3%         |
| MCO14      | Records                                                | Complete               |            |
| **Annually**|                                                      |                        |            |
| ACO1       | Reference dosimetry                                    | 1%                     | 2%         |
| ACO2       | Relative output factor reproducibility                 | 1%                     | 2%         |
| ACO3       | Central axis depth dose reproducibility                | 1%                     | 2%         |
| ACO4       | Wedge transmission factor reproducibility             | 1%                     | 2%         |
| ACO5       | Accessory transmission factor reproducibility         | 1%                     | 2%         |
| ACO6       | Output reproducibility vs. gantry angle                | 1%                     | 2%         |
| ACO7       | Beam symmetry reproducibility vs. gantry angle         | 2%                     | 3%         |
| ACO8       | Timer linearity                                        | 1%                     | 2%         |
| ACO9       | Shutter error                                          | 0.03 min.              | 0.05 min.  |
| ACO10      | Collimator rotation isocenter                          | 2                      | 3          |
| ACO11      | Gantry rotation isocenter                              | 2                      | 3          |
| ACO12      | Couch rotation isocenter                               | 2                      | 3          |
| ACO13      | Coincidence of collimator, gantry, couch axes         | 2                      | 3          |
| ACO14      | Coincidence of isocenters                              | 2                      | 3          |
| ACO15      | Couch deflection                                       | 3                      | 5          |
| ACO16      | Independent quality control review                     | Complete               |            |
TABLE 5. Quality control tests for multileaf collimators (tolerances and action levels are specified in millimeters unless otherwise stated)

| Designator | Test | Performance |
|------------|------|-------------|
|            |      | Tolerance   | Action |

**Patient-specific**

PM1 Verification of transferred data vs. printed template 1 2
PM2 Daily verification of correct data Reproducibility
PM3 Verification of record and verify programming Reproducibility

**Monthly**

MM1 Digitizer check (if used) Functional
MM2 Light and radiation field coincidence 1 2
MM3 Leaf positions for standard field template 1 2
MM4 Electron field interlocks Functional
MM5 Leaf alignment 1 2
MM6 Records Complete

**Yearly**

AM1 Leaf transmission (all energies) Reproducibility
AM2 Leakage between leaves (all energies) Reproducibility
AM3 Transmission through abutting leaves Reproducibility
AM4 Stability with gantry rotation Reproducibility
AM5 Alignment with jaws 1
AM6 Independent quality control review Complete

* May not apply to all designs.

TABLE 6. Quality control tests for electronic portal imaging devices (tolerances and action levels are specified in millimeters unless otherwise stated)

| Designator | Test | Performance |
|------------|------|-------------|
|            |      | Tolerance   | Action |

**Daily**

DE1 Mechanical integrity Functional
DE2 Electrical integrity Functional
DE3 Collision interlocks Functional
DE4 Image quality Reproducibility

**Monthly**

ME1 Positioning in the imaging plane 1 2
ME2 Positioning perpendicular to the imaging plane 10 20
ME3 Image quality Reproducibility
ME4 Artifacts Reproducibility
ME5 Spatial distortion 1 2
ME6 Monitor controls Reproducibility
ME7 Records Complete

**Six monthly**

SE1 Spatial resolution Reproducibility
SE2 Noise Reproducibility
SE3 On-screen measurement tools Reproducibility
SE4 Setup verification tools 0.5 (0.5°) 1 (1°)

**Annually**

AE1 Independent quality control review Complete

IV. DISCUSSION AND CONCLUSIONS

This project has achieved its objectives to date. The largely generic format of the Standards has aided clarity of interpretation and expedited development of the documents—particularly the later documents, which could be composed to fit the format. At some stage in the future, if it is deemed desirable, all the available documents could easily be consolidated into one because so much of the content is generic.
Posting the drafts on an easily accessible web site facilitates feedback and constitutes a method for obtaining a national consensus on the standards. The medical physics community can consider not only the objectives and criteria of the tests, but also the resource implications of adopting the standards. Furthermore, standards approved at this time may easily be updated as new knowledge and equipment become available. Updates can be disseminated almost instantaneously.

The structure of health care delivery in Canada is not conducive to the development of nationally legislated quality control standards, and such legislation is unlikely to be passed in this case. However, once approved and adopted, the standards discussed here may well form an easily monitored component of licensing and accreditation activities applied to cancer treatment facilities.

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Appendix 1

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

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

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

3. Accuracy. Accuracy is the deviation of the measured value of a parameter from its expected or defined value. An example is template positional accuracy.

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

5. Data transfer and validation. Many systems in use in radiation therapy, and elsewhere, rely heavily upon the appropriate data, such as prescription point and wedge orientation, being input and accurately transmitted through the systems. This category of test is intended to confirm that these processes, involving both humans and machines, are being correctly performed.

6. Completeness. The use of this term is restricted to the periodic review of quality control procedures, analysis and documentation.

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

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

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

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