Canadian Association of Provincial Cancer Agencies

Standards for Quality Control at Canadian Radiation Treatment Centres

---

Stereotactic Radiosurgery/Radiotherapy

November 2005

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

Source Documents: **Anita Berndt (Winnipeg)**
Horacio Patrocinio (Montreal)

External Reviewers: **James Beck (Winnipeg)**
Brenda Clark (Vancouver)

Primary Task Group Reviewer: **Peter Dunscombe (Calgary)**

Secondary Task Group Reviewer: **Jean-Pierre Bissonnette (Toronto)**

Task Group Members: Clement Arsenault, Jean-Pierre Bissonnette, Peter Dunscombe (Chair), Jacqueline Gallet, George Mawko, Jan Seuntjens

Document development and review process: The quality control documents in this series originated from one of two sources. Some of the source documents were commissioned by CAPCA specifically for the purpose of developing national standards. This is one such document. Others had been previously developed for provincial use by the Physics Professional Affairs Committee of Cancer Care Ontario (formerly the Ontario Cancer Treatment and Research Foundation). The source documents were developed over an extended period of time from 1989 onwards. Each source document has been reviewed by one or more independent Canadian medical physicists and the reviews accepted by the task group as they became available. The primary and secondary task group reviewers then examined the source document, the external review(s) and any appropriate published literature to propose quality control standards, objectives and criteria to the full task group. The full task group met electronically and, by a consensus approach, developed the present document. The task group gratefully acknowledges the effort contributed by the author(s) of the source document and the reviewer(s) whose work forms the basis of this document. Review, updating and reformatting have been performed and, for any errors or omissions introduced in this process, the task group takes full responsibility.

Table of Contents

Acronyms, Synonyms and Definitions

AAPM	American Association of Physicists in Medicine
ADCL	Accredited Dosimetry Calibration Laboratory
Al	Aluminum
ANSI	American National Standards Institute
BSF	Back-scatter factor
CAPCA	Canadian Association of Provincial Cancer Agencies
CCO	CancerCare Ontario
CCPM	Canadian College of Physicists in Medicine
CNSC	Canadian Nuclear Safety Commission (Successor to the Atomic Energy Control Board - AECB)
COMP	Canadian Organization of Medical Physics
CSA	Canadian Standards Association
CT	Computed Tomography
CTV	Clinical target volume
Cu	Copper
EPI(D)	Electronic portal imaging (device)
FWHM	Full width at half maximum
Gleason score	A numerical system based on major and minor histological patterns
Gy	Gray, unit of absorbed dose (1J/kg)
HVL	Half-value layer
IAEA	International Atomic Energy Agency
ICRU	International Commission on Radiation Units and Measurements
IEC	International Electrotechnical Commission (Geneva, Switzerland)
IMRT	Intensity modulated radiation therapy
INMS-NRCC	Institute for National Measurement Standards of the National Research Council of Canada
IPEM	Institution of Physics and Engineering in Medicine
IPSM	Institute of Physical Sciences in Medicine
ISO	International Organization for Standardization

Isocentre	The intersection of the axes of collimator and gantry rotation
Linac	Electron linear accelerator
MLC	Multileaf collimator
mMLC	mini- or micro-Multileaf Collimator
MPPAC	Medical Physics Professional Advisory Committee
MRI	Magnetic Resonance Imaging
MU	Monitor unit
NCRP	National Council on Radiation Protection and Measurements
NIST	National Institute of Standards and Technology
NRCC	National Research Council of Canada
NTD	Normal treatment distance
ODI	Optical distance indicator
PMMA	Polymethyl methacrylate
PDD	Percentage depth dose
PSA	Prostate specific antigen
PTV	Planning target volume
QA	Quality assurance (the program)
QC	Quality control (specific tasks)
SSD	Source-to-surface distance
SRS	Stereotactic radiosurgery
SRT	Stereotactic radiotherapy
STP	Standard temperature and pressure
TBI	Total body irradiation
TG-	Publications of various AAPM Quality Assurance Task Groups
TLD	Thermoluminescent dosimeter
U	air-kerma strength (μGy m^2/h)
WHO	World Health Organization
σ	Standard deviation
ε_T	Timer/monitor end error

Frequencies:

Daily:	Once during every treatment day and separated by at least 12 hours.
Weekly:	On average once every 7 days and at intervals of between 5 and 9 days.
Monthly:	On average once every four weeks and at intervals of between 3 and 5 weeks.
Quarterly:	On average once every three months and at intervals of between 11 and 15 weeks.
Annually	On average once every 12 months and at intervals of between 10 and 14 months.

Output:

Output constancy check: a daily instrument reading (corrected for temperature and pressure) taken under reproducible geometrical conditions designed to check that the radiation output (e.g. cGy/MU) values in clinical use are not grossly in error.

Output Measurement: a determination of the absorbed dose to water (cGy) at a reference point in the photon beam for a chosen field size and beam quality.

Introduction

Patients receiving treatment in a Canadian health care facility have a reasonable expectation that the quality of their treatment is independent of their geographic location or the centre they are attending. Insofar as medical physicists contribute to treatment quality, this expectation will be more closely met through the harmonisation of quality control standards across the country. The Canadian Association of Provincial Cancer Agencies (CAPCA) has initiated the process of standardisation of treatment quality in Canada through its draft document "Standards for Quality Assurance at Canadian Radiation Treatment Centres". This present document is an appendix to the CAPCA document and is concerned with quality control standards for stereotactic radiosurgery/therapy programs. There are two approaches to the stereotactic therapeutic application of ionizing radiation: Gamma Knife® and linac based techniques. These are described separately in this document which was specially commissioned for this quality control series.

A quality control program on equipment used for radiosurgery/therapy in a Canadian health care facility must be carried out by, or under the direct supervision of, a qualified medical physicist. Here, a qualified medical physicist is a physicist who is certified in Radiation Oncology Physics by the Canadian College of Physicists in Medicine or who holds equivalent certification. This individual, known as the supervising physicist, is responsible for ensuring compliance with the local quality control protocol, maintaining appropriate documentation, taking appropriate remedial actions and communicating with other members of the team concerning the operational state of the equipment. Depending on local circumstances and organisational structure, one physicist may supervise quality control on all equipment or the responsibilities may be dispersed. However, the supervising physicist for a particular piece of equipment must have a direct line of communication to the Quality Assurance Committee for the Radiation Treatment Program.

This document contains specific performance objectives and criteria that the equipment should meet in order to assure an acceptable level of treatment quality. However, it does not recommend how the tests should be carried out. It is the responsibility of the supervising physicist to ensure that the locally available test equipment and procedures are sufficiently sensitive to establish compliance or otherwise with the objectives and criteria specified here. There are many publications dealing with the performance, specifications and quality control of both Gamma Knife units (AAPM 1995; Maitz, 1995; Walton, 1987; GK® User Manual, Wu, 1992; Wu, 1990; Yu, 2001) and linac-based stereotactic radiosurgery equipment (AAPM 1995; Hartmann 1995, Tsai 1991, Drzymala 1991, Lutz 1988, Serago 1991). Some of these publications have detailed descriptions of how to conduct the various quality control tests.

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

A successful quality assurance program is critically dependent upon adequately trained staff and a culture of continuous quality improvement. Educational opportunities to be offered to quality control staff must include new staff orientation, in-house continuous education, conference participation and manufacturer's courses as appropriate. All such educational activities must be documented as part of the quality assurance program. Continuous quality improvement embodies the concepts of documentation, monitoring, review and feedback.

The standards promoted in this document are based on the experience of the authors and reviewers and are broadly consistent with recommendations from other jurisdictions (AAPM 1995; Hartmann 1995; Maitz, 1995). Although this document has undergone extensive review it is possible that errors and inaccuracies remain. It is hoped that the users of these standards will contribute to their further development through the identification of shortcomings and advances in knowledge that could be incorporated in future versions.

Performance Objectives and Criteria

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

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

3. Accuracy. Accuracy is the deviation of the measured value of a parameter from its expected or defined value. Examples are isocentre diameter and reference dosimetry (cGy/MU).

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

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

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

i. Tolerance Level. For a performance parameter 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 to that performance parameter.

ii Action Level. If the difference between the measured value and its expected or defined value exceeds the action level then a response is required immediately. The ideal response is to bring the system back to a state of functioning which meets all tolerance levels. If this is not immediately possible, then the use of the equipment must be restricted to clinical situations in which the identified inadequate performance is of no or acceptable and understood clinical significance. The decision on the most appropriate response is made by the supervising physicist in conjunction with the users of the

equipment and others as appropriate. If the difference between the measured value and its expected or defined value lies between the tolerance and action levels, several courses of action are open. For a problem that is easily and quickly rectifiable, remedial action should be taken at once. An alternative course of action is to delay remedial intervention until the next scheduled maintenance period. Finally, the decision may be made to monitor the performance of the parameter in question over a period of time and to postpone a decision until the behaviour of the parameter is confirmed. Once again, this will be a decision made by the supervising physicist in consultation with the users of the equipment and others as appropriate.

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

Systems Descriptions

Stereotactic radiosurgery (SRS) is a brain irradiation technique used in the treatment of benign and malignant lesions, vascular malformations, and various functional conditions. The name originates from the use of "stereotaxy" or spatially accurate three-dimensional localization and from the spatially accurate and confined radiation delivery such that the prescribed radiation dose can be delivered in a single fraction with minimal irradiation of surrounding tissues, hence "radiosurgery". Typical radiosurgery doses can range from 10-25 Gy, though some clinical sites such as trigeminal neuralgia may require much higher doses. Safely delivering such doses usually requires the use of an invasive immobilization frame fixed to the patient's skull. The term "stereotactic radiotherapy" (SRT) refers to a treatment delivery where the prescribed dose is delivered in several fractions (typically 2-30) but nonetheless using a stereotactic coordinate system approach. However, due to the lower fraction doses, less rigid immobilization systems are available. These typically consist of thermoplastic masks or ear and nose bridge immobilizers.

A. Linac-based SRS/T

Several linac-based SRS approaches have been developed over the years. Most traditional approaches involve the use of one or more non-coplanar arc irradiations using circular collimators to define a spherical "shot" of radiation in the area of beam intersection. Collimator sizes typically range from 0.5-4.0 cm in diameter. Irregular lesions can be treated by superimposing several such "shots" at different positions over the tumour volume. Techniques based on this approach include a the use of non-co-planar arcs (between 4 and 11) and a dynamic rotation technique and use photon beam energies in the range of 6-10MV. Reviews of the characteristics of several treatment techniques can be found in the literature (Podgorsak 1989, Schell 1991) More recently, static conformal beams defined by custom shaped collimators or a mini- or micro-multileaf collimator (mMLC) have been used in SRS(Clark 2001). Finally, in the last few years, intensity-modulated mMLC SRS has also been introduced.

The overall achievable standard deviation of positional uncertainty in SRS is on the order of 2-4 mm (AAPM 1995) and depends on (1) target definition and (2) tolerances of the dose delivery apparatus (including the immobilizing frame). The characteristics of most linear accelerators are such that these cannot be used directly for SRS without additional considerations or modifications. These include the addition of tertiary collimators that define the SRS beams, and the modification of the linac couch or introduction of a pedestal mount to improve axis alignment and to support the immobilizing frame. Therefore, a general QC program developed for linear accelerators may not ensure that the above overall SRS uncertainty requirements are met. This document presents guidelines for a SRS QC program that are intended to supplement a QC program for linear accelerators. The QC of MLCs (of which mMLCs are a subgroup) and IMRT are beyond the scope of this document and addressed in separate dedicated Appendices.

The typical SRS procedure begins with the attachment of the invasive head frame to the skull by a physician. The purpose of the frame is to (1) establish a fixed coordinate system within the patient's skull; and, (2) facilitate patient positioning and immobilization during imaging and treatment. The patient can be imaged using CT, MRI angiography and other modalities, depending upon the site. In at least one imaging modality (typically CT), a suitable fiducial box is attached to the head frame. Fiducial markers appearing in the images are used by the treatment planning system to establish a coordinate system. Other imaging modalities can also be used, either with their own specific localization boxes or through an image fusion process. The target can then be drawn on the appropriate imaging study and reconstructed in the three dimensional coordinate space defined by the frame. Radiation spheres or beams of different size, relative weight, and position are combined to achieve conformal coverage of the tumour volume. At the treatment, the patient's head frame is fixed to the support and aligned to the correct position using wall lasers. If multiple radiation shots are involved, the patient must be realigned to the isocentre prior to the next radiation shot.

Today, many commercial and in-house SRS programs have also introduced non-invasive immobilization systems destined for stereotactic radiotherapy (SRT) as described earlier. Since SRT systems do not necessarily maintain the patient at the same position in the frame coordinate space from day to day, it is up to each institution to assess the overall uncertainty associated with their use and to incorporate this uncertainty into the treatment planning process in the form of a suitable PTV margin (Robar et al. 2005).

This document will assume that the institution is introducing a program based on a SRS/SRT solution purchased from a vendor (linac modifications and treatment planning), particularly when discussing the acceptance test procedure. If the institution is introducing an in-house developed program then it must devise a similar acceptance test procedure of its own.

B. Gamma Knife SRS/T

The GK contains 201 ^{60}Co sources arranged in five concentric rings. The sources are shielded by a 43 cm thick hemispherical iron shell (GK® Site Planning Guide). Primary collimation is provided by beam channels within an inner concentric hemispherical shell. The beam channels are constructed to have a common focus point (radiation isocenter) which results in an approximately spherical treatment volume, centred in the hemispherical shell. No primary radiation exits the GK; scattered radiation is blocked by shielding doors which rotate out of the way during treatments. Spherical dose deposition regions of different radii are generated using secondary collimation in the form of four interchangeable collimator helmets (4, 8, 14 or 18 mm single beam profile FWHM). The helmet is attached to the treatment couch. To initiate a treatment the shielding doors open and the couch and helmet move into the GK. The helmet has "docked" when the primary and secondary collimators align, providing an unobstructed path for the radiation to reach the patient.

Stereotactic techniques are employed to ensure that the lesion is treated while the critical structures are spared. To achieve this, a rigid head frame is attached to the skull to (a) establish a fixed coordinate system within the patient's skull; and, (b) facilitate patient

positioning and immobilization during treatment. The patient is imaged using MRI, CT and/or angiography, depending upon the treatment indication. In each case, a modality specific fiducial box is attached to the head frame. Fiducial markers appearing in the images are digitized using the treatment planning system, and used to establish a coordinate system. Radiation spheres of different size, relative weight, and position are combined to achieve conformal coverage of the lesion. Dose is calculated at any point within the patient by summing the attenuated single beam profiles. If necessary, critical structure doses can be reduced by replacing selected collimator openings with solid plugs. During the treatment the patient's head is positioned using the manual or automatic positioning system, which is itself fixed to the collimator helmet. The shielding doors open and the helmet docks with the primary collimation assembly for the duration of the treatment for the first isocentre (referred to as a "shot"). Once the treatment time for the shot has elapsed, the patient is retracted and their head is moved to the next treatment position. This procedure is repeated until all shots have been treated.

The GK is manufactured to very high tolerances. The only measurement required for the treatment planning computer is the dose rate $\dot{D}_{18}$ for the largest collimator helmet (18 mm single beam profile FWHM). The dose rate for the other three helmets (4, 8, 14 mm single beam profile FWHM) is calculated using $\dot{D}_i = \dot{D}_{18} \cdot HF_i$ (i = 4, 8, 14) where *HF* is the helmet (output) factor. Although it is possible to use customized values, it has become standard practice to use the *HF* values recommended by Elekta. The beam profiles used for dose calculations are hard-coded into the treatment planning system.

Acceptance Testing and Commissioning

Linear accelerators or Gamma Knives that are newly acquired, have been modified to perform SRS/T (linacs) or substantially upgraded require acceptance testing and commissioning before being put into clinical service.

Acceptance testing and commissioning has several purposes:

- to ensure that the stated specifications or equipment and performance are achievable,
- to establish baseline parameters for the future SRS/T quality assurance program,
- to familiarize the customer with operation of the unit.

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

Acceptance tests are customarily described in an acceptance test procedure document prepared by the vendor, although the purchaser may wish to specify additional tests. Guidelines for acceptance testing in SRS/T can be found in the literature. The document is signed by the purchaser upon satisfactory completion of testing, before which formal purchase of the unit should not be completed.

The standards for SRS/T delivery systems acceptance testing should be consistent with routine quality control objectives and criteria. As such, the system should meet or exceed the Tolerance Levels detailed later in this document (Tables 1a and b). The tests should be performed by, or under the supervision of, a qualified medical physicist. Adherence to these standards (Tables 1a and b) must be demonstrated and documented, in or outside of the vendor's acceptance testing protocol, before the system is put into clinical service.

Also, an appropriate subset of acceptance tests must be performed after any repair or preventive maintenance interventions on the system. The extent of testing required must be judged by a qualified medical physicist, and in the context of this document, must include any items that may have an impact on the performance and accuracy of the SRS/T program.

Commissioning generally refers to the acquisition of additional measured data from a unit after acceptance testing, with two purposes:

- to acquire data required for dose calculation and for the treatment planning process,
- to establish additional baseline parameters for the quality control program.

The specific commissioning measurements required will depend on the SRS/T equipment, program and technique that are adopted. The manufacturer usually makes recommendations on system specific commissioning measurements but the physicist can

refer to sources in the literature as well (AAPM 1995, Hartmann 1995; Maitz, 1995). Due to the complexities of small field dosimetry, it is important to give great consideration to the choice of radiation detector that is used for each type of radiation measurement. For example, a large volume ion chamber (0.6 cm^3) may be suitable for reference dosimetry and measuring output factors for larger field sizes, but is inappropriate for measuring small field output factors or beam profiles. The physicist responsible for the SRS program can refer to numerous publications discussing the difficulties of small-field dosimetry in the literature. The resulting data should be compiled into a commissioning document that would allow future physicists the ability to compare their own measured data with the initial commissioning set.

Gamma Knife® commissioning measurements are very different from those performed for a linear accelerator for two reasons: first, the geometry of the system is such that a large number of beams are coming in from many angles to generate an approximately spherical dose distribution. Measurements with a conventional rectangular dosimetry phantom are therefore not useful. Second, the Gamma Knife® has no moving collimator jaws or wedges; the only beam modifiers are plugs, which can be used to block selected collimator apertures. All components are precisely machined so that the dose profiles for all Gamma Knife® units are virtually identical, which allows a standard set of profiles and helmet (output) factors to be hard coded into the treatment planning computer. Profile and helmet factor measurements are performed solely for verification purposes.

It is essential to recognize that commissioning SRS/T techniques involves more than just ensuring that the equipment itself works properly. The whole treatment chain, including the measuring, imaging modalities and treatment planning system must be tested in addition to the delivery unit and the SRS/T tools. Clearly all the tests listed in Table 1 must be performed at acceptance and commissioning time with the intended local test equipment and protocols if meaningful baselines are to be established.

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.

The standards for linac-based SRS/T quality control are listed in Table 1. These minimum standards consist of tests to be performed, along with their minimum frequency. The tests required are a combination of those recommended by the acceptance testing procedures of vendors, scientific literature and good physics practice. The standards rely heavily on the recommendations established by AAPM 1995 and Hartmann 1995, both the result of collaborative working groups.

The tests should be performed by a qualified medical physicist, or a suitably trained individual working under the supervision of a qualified medical physicist. Independent verification of the results of quality control tests is an essential component of any quality control program. To ensure redundancy and adequate monitoring, a second qualified medical physicist must independently verify the implementation, analysis and interpretation of the quality control tests at least annually. This independent check must be documented.

Daily tests must be scheduled prior to the first SRS/T treatment of the day, or in some cases prior to every treatment if equipment is removed from a linac (ex. Tertiary collimator assembly). For other, less frequent tests, testing at less than the minimum frequency is permissible only if experience has established that the parameters of interest are highly stable. Documentary evidence supporting this decision is essential.

In the event that the equipment does not meet the stated action level criteria, an immediate adjustment or repair should be effected. If it is not immediately possible to restore the equipment to full performance, then the use of the equipment must be restricted to clinical situations in which the identified inadequate performance is of no or acceptable and understood clinical significance. The decision on the most appropriate response is made by the supervising physicist in conjunction with the users of the equipment and others as appropriate

Preventive maintenance schedules and interventions as recommended by the manufacturer of the equipment should be adhered to diligently. Following preventive maintenance or repair, the appropriate quality control tests selected from those listed in Table 1 must be performed before the unit is returned to clinical service. The extent of testing required must be judged by a qualified medical physicist. Frequently, machine repairs and quality control testing are performed by different persons. In such cases, good communication and reporting between the various staff involved are essential.

As pointed out previously, radiation safety activities are beyond the scope of this report. However, such activities may be integrated into routine quality control programs of equipment.

Documentation

Appropriate documentation is an essential component of a quality assurance program. All documents associated with the program should contain, as a minimum, the following information:

1. the name of the institution
2. the name of the originating department
3. the name(s) of the document's author(s)
4. the name of the individual(s) or group who approved the document for clinical use
5. the date of first issue
6. the number and date of the current revision

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

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

The quality control protocol contains the standards, or performance objectives and criteria, to be applied to a piece of equipment. Such standards are based on documents such as this one. In addition to the specification of standards, the protocol should provide sufficient detail concerning the test equipment and procedures to be followed that there can be 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, it is essential to have a means of documenting any corrective action that takes place, together with any subsequent tests. Deviations from the locally approved protocol, such as those resulting from clinical pressure to access the equipment, must, of course, also be documented.

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

Table 1a: Quality Control Tests for Linac-based SRS/T

Designator	Test	Performance	
		Tolerance	Action
Patient Specific*			
PSL1**	Patient monitoring system	Functional	
PSL2**	Machine interlocks (as appropriate)	Functional	
PSL3	Collision tests	Functional	
PSL4	Imaging parameter check	Appropriate	
PSL5	MU calculation (independent check)	3%	
PSL6**	Couch/Pedestal Locking	Functional	
PSL7**	Cone alignment (if appropriate)	0.5 mm	0.75 mm
PSL8	Field shape check (if appropriate)	0.5 mm	0.75 mm
PSL9	Target coordinate check	0.75 mm	1 mm
PSL10**	Laser check	0.75 mm	1 mm
PSL11	Head Frame motion	1 mm	1 mm
PSL12	Checklist use	Documented	
Quarterly			
QSL1	Isocentre wobble diameter (gantry)	0.5 mm	0.75 mm
QSL2	Isocentre wobble diameter (couch)	0.5 mm	0.75 mm
QSL3	Couch and gantry axis coincidence	0.5 mm	0.75 mm
QSL4	Collimator wobble diameter	0.5 mm	0.75 mm
QSL5	Records	Complete	
Annually			
ASL1	Acceptance functional tests	Functional	
ASL2	Percentage depth dose	2%	2%
ASL3	CT localization performance	1.5 mm	1.5 mm
ASL4	MRI localization performance	2 mm	2 mm
ASL5	Angiography localization performance	1 mm	1 mm
ASL6	Dose profiles (FWHM)	1 mm	1 mm
ASL7	Dose delivery test	2%	5%
ASL8	Output factors	2%	3%
ASL9	Radiation/mechanical isocentre coincidence	0.5 mm	0.5 mm
ASL10	Known target test (CT-based)	1 mm	1.5 mm

*Patient specific tests are to be carried out for every SRS patient subject to the note (**) below. For SRT the minimum frequencies are different. Tests PSL1, PSL2, PSL6, PSL7, and PSL12 are for every fraction, tests PSL3, PSL4 and PSL5 before the first fraction and tests PSL8, PSL8, PSL9 on a weekly basis. Test PSL11 is not applicable in SRT provided a suitable PTV margin is being used in the treatment planning process. It can also be omitted for SRS if it is determined during commissioning that head frame slippage is well below the suggested tolerance for the given frame. Test PSL12 can also be omitted if a record and verify system is used for the dose delivery.

**Denotes patient-specific tests that can be carried out on a daily basis if treating more than one patient per day provided that the SRS apparatus is not moved/removed between patients

Notes

Patient-specific Tests

PSL1	A camera and audio intercom system must be functional. This is to ensure that the patient can be seen and heard at all times.
PSL2	Test the functioning of machine interlocks that are affected by the SRS delivery (ex. Interlock that stops irradiation at the end of an arc)
PSL3	Test that all gantry/couch motions to be activated remotely can actually occur without colliding with the patient. This is particularly of concern with mMLC systems and static fields where some planned fields may not be deliverable.
PSL4	To ensure that imaging parameters are appropriate to the site being treated (ex. Imaging a 1.2 cm acoustic neuroma using MRI with 5 mm slices may lead to significant volume averaging)
PSL5	Check performed and signed by a second physicist
PSL6	This is a functional test to ensure that any locking mechanisms on the couch or pedestal mount are work properly
PSL7	Relevant if the cone position is not fixed with respect to the collimator axis. Can be performed using film at opposing angles for example.
PSL8	This test is relevant for field shapes that are defined by custom blocks and mMLC. The test can be performed by checking projections against a printout of field projections from the treatment planning system at a given distance
PSL9	The type of test performed may vary from system to system and may be as involved as placing some object at a known position outside the skull and determining the coordinates in fiducial space or as simple as physically verifying the coordinates on the printout attached to the localization box and comparing to the plan.
PSL10	The most common method of checking laser alignment to the isocentre at different gantry/couch angles is that suggested by Winston and Lutz (1998)
PSL11	Head frame motion can be assessed using a depth helmet that measures SSD at different entry points and compares to CT determined SSDs or SSDs previously measured using the depth helmet. Other methods can also be found in the literature or may be suggested by the vendor
PSL12	A checklist containing all the steps in the procedure and appropriate signatures of tasks completed should be included in the chart.

Quarterly Tests

QSL1	Can be verified using a mechanical pointer and a dial gauge for example. If a less precise method is used for this test, or for MSL2-MSL4, a mean error of repeated measurements (possibly by different physicists) can be used to compare with the tolerance levels. The actual measured values must, however, lie below the action level.
QSL2	Same as above, but for couch rotation.
QSL3	Can be assessed together with MSL1 and MSL2 above
QSL4	Can be assessed using the same setup as the previous or simply with a piece of graph paper and a mechanical pointer
QSL5	Documentation relating to the daily quality control checks, preventive maintenance, service calls and subsequent checks must be complete, legible and the operator identified

Annual tests

ASL1	Repeat all functional acceptance tests which are not performed during daily quality assurance
ASL2	PDD measured using a suitable detector for each field size (cones or standard mMLC sizes)
ASL3	Can be assessed as for MSL5 but at several known positions
ASL4	Similar to ASL3 but for MRI. If MRI is used through an image fusion process only (no fiducials on the MRI), then in addition to this annual test, MRI fusion must be evaluated an approved by the physician on a per-patient basis
ASL5	Similar to ASL3 but for angiography.
ASL6	Dose profiles measured with a suitable small detector. Tolerance and action levels refer to the difference in width of the 50% isodose line (where central axis = 100%)
ASL7	A test where an SRS plan is generated for a phantom in which a detector can be placed and a dose measured. The plan is delivered and the resulting measurement compared with the predicted value.
ASL8	Factors relating output for a given cone size or mMLC field with a reference field size (ex. 10 x 10 cm^2). Compared with values in the TPS.
ASL9	A complete set of isocentre coincidence tests including radiation and mechanical isocentre coincidence for all three motions (collimator, couch, gantry)
ASL10	Can be assessed by CT scanning a known small target object, planning a treatment and verifying that the coordinates determined correspond to the target, for example.

Table 1b: Quality Control Tests for Gamma Knife SRS/T

Designator	Test	Performance	
		Tolerance	Action
Daily			
DSG1	Door interlock/last person out/radiation on lights	Functional	
DSG2	Audio and visual contact with the patient	Functional	
DSG3	Alarm test	Functional	
DSG4	Machine interlocks (helmet cap, patient protection, helmet changer)	Functional	
DSG5	Helmet indicator and interlock	Functional	
DSG6	Treatment initiate / timer terminate	Functional	
DSG7	Treatment timer	See Table 2	
DSG8	System status indicator on console	Functional	
DSG9	Treatment pause and resume	Functional	
DSG10	Emergency stop and reset	Functional	
DSG11	Couch out	Functional	
DSG12	APS QA	GK manual	
DSG13	Imaging QA	Variable[1]	
DSG14	LGP QA	Functional	
DSG15	MU Calculation (Independent check)	3%	
Weekly			
WSG1	External Pause	Functional	
WSG2	Helmet indicator, helmet cap sensor, helmet microswitches	Functional	
WSG3	Trunnion test (test only helmets actually used for trunnion treatments)	0.1 mm	
Monthly			
MSG1	Extended alarm test	Functional	
MSG2	Machine interlocks (couch emergency release, helmet changer in sensor, helmet trolley sensor, helmet changer down sensor, mattress squeeze protection)	Functional	
MSG3	UPS battery check	Functional	
MSG4	Timer linearity	1%	3%
MSG5	Timer constancy	1%	3%
MSG6	Shutter correction	0.01 min.	0.03 min
MSG7	Timer accuracy	See Table 2	
MSG8	Radiation output	1%	3%
MSG9	Thermometer, barometer, ion chamber QA	CAPCA standards	
MSG10	Documentation	Complete	

[1] Tolerances should reflect the dose being delivered and the eloquence of the treatment site.

Annually			
ASG1	Acceptance functional tests	Functional	
ASG2	Calibration (AAPM 1983)		
ASG3	Dose profiles	1 mm at 50%	
ASG4	Helmet factors	3%	5%
ASG5	Radiation/mechanical isocentre coincidence	0.5 mm	

Table 2: Timer Accuracy Tolerance Values*

Time (minutes)	Tolerance (sec)	Tolerance % Error in Dose	Action (sec)	Action % Error in Dose
0.5[κ]	0.3	1.0	0.6	2.0
1.0[β]	0.6	1.0	1.0	1.7
$1.0 < t < 30.0$	Interpolate between tolerance and action levels for 1.0 and 30.0 minutes			
30.0[β]	3	0.2	5	0.8
$30.0 < t < 60.0$	Interpolate between tolerance and action levels for 30.0 and 60.0 minutes			
60.0[β]	5	0.1	10	0.3

*Tolerance values chosen on the basis of Elekta recommendations[β] and the requirement that timer inaccuracies do not produce an error of more than 1% (Tolerance) and 2% (Action) [κ].

Notes

Daily Tests

DSG1,2 The configuration of these tests will depend on the design of the facility and equipment. Safety is the concern and tests should be designed accordingly. As a minimum, manufacturer's recommendations and applicable regulations must be followed.

DSG3 Perform test as described in the GK User Manual (GK® User Manual).

DSG4 Initiate conditions for the interlock to occur. Ensure that the treatment can not commence when the interlock is active.

DSG5 Ensure that the mounted helmet is correctly indicated; ensure that selecting the incorrect helmet generates an error message.

DSG6 When no interlocks are engaged the treatment starts; the treatment stops once the requested time has elapsed.

DSG7 The treatment timer agrees with stopwatch values to within tolerance.

DSG8 The system status indicator on the computer monitor is correct.

DSG9,10,11 Features function as described in the GK User Manual (GK® User Manual).

DSG12 Perform test as described in the GK User Manual (GK® User Manual).

DSG13 Imaging quality assurance will vary between institutions, and depends to some degree upon the phantom(s) being used. Tolerances should reflect the dose being delivered and the eloquence of the treatment site. Note also that it may not be necessary to test all aspects of an imaging system daily. Parameters which are less likely to vary and / or are less crucial for lesion localization can be tested less frequently (AAPM 1995).

DSG14 Perform a test which checks the decayed daily dose rate.

DSG15 Check performed and signed by the physicist.

Weekly Tests

WSG1 Initiate conditions for the interlock to occur. Ensure that the treatment can not commence when the interlock is active.

WSG2 For the three unmounted helmets, test the helmet indicator, helmet cap sensor and helmet microswitches using the helmet test box as described in the GK User Manual (GK® User Manual). For the mounted helmet, test the helmet indicator and helmet cap sensor in situ. Test the helmet microswitches by securely taping a 0.1 mm shim to each of the helmet docking surfaces and ensure that both helmet microswitches fail to dock when a treatment is initiated (AAPM 1995). Rotate through all four helmets such that each helmet is tested in situ at least once per month.

WSG3 Perform test as described in the GK User Manual (GK® User Manual).

Monthly Tests

MSG1 Verify that the mute button only silences the audible alarm for ~2 minutes.

MSG2 Initiate conditions for the interlock to occur. Ensure that the treatment can not commence when the interlock is active.

MSG3 Perform the following tests:

- UPS test as described in the GK User Manual (GK® User Manual).
- Ensure that a treatment pause is initiated after 1 minute when the mains power is turned off.
- Ensure that a new treatment can not be initiated until the mains power has been restored.

MSG4 Ensure that ion chamber measurements performed over the range of times expected during actual treatments vary linearly with treatment time.

MSG5 Ensure that successive ion chamber measurements for the same treatment time are reproducible.

MSG6 Ensure that the shutter correction does not exceed the stated tolerances. A shutter correction tolerance value of 0.01 minutes was chosen to ensure that the shutter does not produce an error of more than 1% for a 1.0 minute

irradiation (most irradiations are longer than a minute). The treatment planning computer assumes that the shutter correction is negligible.

MSG7 Check the timer accuracy for the range of treatment times in test MSG4 using a stop watch.

MSG8 Ensure that the radiation output, corrected for decay agrees with the calibration value.

MSG9 Test the accuracy of the thermometer, barometer and ion chamber using established institutional procedures. Refer to CAPCA standard for major dosimetry equipment.

MSG10 Documentation relating to the daily quality control checks, preventive maintenance, service calls and subsequent checks must be complete, legible and the operator identified

Annual tests

ASG1 Repeat all functional tests which are not performed during daily, weekly or monthly quality assurance.

ASG2 Calibrate the Gamma Knife.

ASG3 Measure the dose profiles using the procedure described in the GK User Manual (GK® User Manual) as a guideline.

ASG4 Measure the helmet factors using an appropriately sized dosimeter such as 1 x 1 x 1 mm^3 TLDs.

ASG5 Measure the isocentre coincidence using the procedure described in the GK User Manual (GK® User Manual) as a guideline.

References and Bibliography

AAPM 1983. "Report of Task Group 21: A protocol for the determination of absorbed dose from high energy photon and electron beams." *Med. Phys.* **10**, 741-771.

AAPM 1995. "Stereotactic Radiosurgery, Task Group 42 Radiation Therapy Committee", American Institute of Physics, New York.

Clark, B.G., Robar, J.L. and Nichol, A.M. (2001). Analysis of treatment parameters for conformal shaped field stereotactic irradiation: comparison with non-coplanar arcs. *Phys. Med. Biol.* **46,** 3089-3103

Drzymala, R. (1991) "Quality assurance for linac-based stereotactic radiosurgery" in *Quality assurance in radiotherapy physics*, Proc. American College of Medical Physics Symp.edited by Starkshall G. and Horton J. (Medical Physics Publishing).

GK® Site Planning Guide (2001): Leksell Gamma Knife® Model C Site Planning Guide, Art. No. 908920 Ed. 1, Elekta Instruments AB, Stockholm, Sweden.

GK® User Manual (2002): Leksell Gamma Knife® C Instructions for Use, Art. No. 011275 Rev. 00, Elekta Instruments AB, Stockholm, Sweden.

Hartmann, G. (1995), "Quality assurance program on sterotactic radiosurgery: Report form a quality assurance task group", Springer.

ISO 9001 1994 BS EN ISO 9001: (1994) Quality Systems. Model for Quality Assurance in Design, Development, Production, Installation and Servicing (British Standards Institute, London).

Lutz W., Winston K., Maleki N. (1988), "A system for stereotactic radiosurgery with a linear accelerator", *Int. J. Radiat. Oncol. Biol. Phys.* **14**, 373.

Maitz, A. H., A. Wu, L. D. Lunsford, J. C. Flickinger, D. Kondziolka, W. D. Bloomer (1995), "Quality assurance for gamma knife stereotactic radiosurgery", *Int. J. Radiat. Oncol. Biol. Phys.* **32**, 1465-1476.

Podgorsak E., Pike B., Olivier A. (1989), "Radiosurgery with high energy photon beams: a comparison among techniques", *Int. J. Radiat. Oncol. Biol. Phys.* **16**, 857.

Quality Management Systems – Requirements, Ed 1, (2000), (International Organization for Standardization, Geneva)

Robar, J.L., Clark, B.G., Schella, J.W. and Kim, C.S. (2005). Analysis of patient repositioning accuracy in precision radiation therapy using automated image fusion. *J. App. Clin. Med. Phys.* 6 . 71-83.

Schell M., Smith V., Larson A., Wu A., Flickinger J. (1991), "Evaluation of radiosurgery techniques with cumulative dose-volume histograms in linac-based stereotactic external beam irradiation", *Int. J. Radiat. Oncol. Biol. Phys.* **20**, 1325.

Serago C., Lewin A., Houdek P., Gonzalez-Arias S., Hartmann G., Abitbol A., Schwade J. (1991), "Stereotactic target point verification of an x-ray and CT localizer", *Int. J. Radiat. Oncol. Biol. Phys.* **20**, 517.

Tsai J-S., Buck B., Svensson G., Alexander E., Cheng C-W., Mannarino E., Loeffler J. (1991), "Quality assurance in stereotactic radiosurgery using a standard linear accelerator", *Int. J. Radiat. Oncol. Biol. Phys.* **21**, 737.

Walton, L, C. K. Bomford, D. Ramsden (1987), "The Sheffield stereotactic radiosurgery unit: Physical characteristics and principles of operation", *Br. J. Radiol.* **60**, 897-906.

Wu, A., G. Lindner, A. Maitz, A. M. Kalend, L. D. Lunsford, J. C. Flickinger, W. D. Bloomer (1990), "Physics of gamma knife approach on convergent beams in stereotactic radiosurgery", *Int. J. Radiat. Oncol. Biol. Phys.* **18**, 941-949.

Wu, A. (1992), "Physics and dosimetry of the gamma knife." *Neurosurg. Clin. N. Am.* **3(1)**, 35-50.

Yu, C., Z. Petrovich, M. L. J. Apuzzo and G. Luxton (2001), "An image fusion study of the geometric accuracy of magnetic resonance imaging with the Leksell stereotactic localization system", *J. App. Clin. Med. Phys.* **2**, 42-50.