Swiss Society of Radiobiology and Medical Physics

Quality Control of Medical Electron Accelerators

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Contents

1 Introduction

The aim of the recommendations described in this document is to provide medical physicists working in radiation therapy departments with guidelines on which to base Quality Assurance programmes for medical electron accelerators as required by the Radiological Protection Act [1], the Radiological Protection Ordinance [1] and the "Beschleunigerverordnung, BeV" [2]. These Recommendations replace in part (medical electron accelerators only) the Recommendations No 1 1982 and Revision 1992 of the Swiss Society of Radiobiology and Medical Physics (SSRMP) [3] and updates the Recommendations No 11 from 2003.

For the preparation of the present recommendations, it was decided to rely as much as possible on published national and international guidelines, with particular reference to those listed in chapter 11 [4-21]. The structure of this document is intended to be as general as possible, in order that the recommended procedures may be applied in all Swiss radiation therapy departments. At the same time, the document aims to introduce a reasonable level of uniformity for quality assurance methods throughout Switzerland. Whenever a *medical physicist* is addressed within this recommendation, a SSRMP certified or equivalent foreign certificated medical physicist accepted by the SSRMP is meant.

This document addresses mechanical, dosimetric and safety tests on linear accelerators (photons and electrons). Determination of absolute dose under reference conditions is not within the scope of this recommendation. For the dosimetry of high energy photon and electron beams the user should refer to Recommendations No. 8, 2000 [10] and No. 10, 2002 [11] of the SSRMP.

It should be noted that the tests described here are considered insufficient for the following situations:

- acceptance and commissioning of new equipment,
- acceptance following major corrective interventions, or after major upgrades,
- acquisition of data directly used for treatment planning.

For those situations that are beyond a routinely performed quality assurance of a medical linear accelerator exists different international accepted procedures as e. g Ref [5], Recommendation Nr. 7 of SSRMP 1997 or the report of TG-106 of the Therapy Physics Committee of the American Association of Physicists in Medicine 2008 [18].
Whenever possible, standard set-up conditions have been proposed and suggestions made about equipment to be used. These suggestions should be considered as recommendations and not as mandatory requirements. It is recommended that specific procedures be written by a medical physicist for any tests used which differ substantially from the ones described in this document.

It should also be noted that it may be unrealistic to carry out some of the tests described in this document in certain centres because the item being tested is not available, or is not in clinical use. It remains the responsibility of a qualified medical physicist to apply these recommendations in a suitable manner.

It is also recommended that the magnitude of any deviations from the reference value proposed within this document is recorded for each test, rather than simply using a tick to confirm that the test has been carried out and that the results lie within the allowed tolerance limits. This enables trends to be seen, which may allow action to be taken before the tolerances are exceeded.

A certain degree of overlap between some of the described tests is unavoidable. It is the responsibility of a qualified medical physicist to combine the tests such that all aims are covered.

Some of the checks could be delegated to other co-workers (technicians, medical radiation technologists or other suitably trained employees). The limits of such delegation are left to the responsibility of the medical physicist. The Quality Assurance programme itself, nevertheless, remains the responsibility of the medical physicist.

It is a legal requirement that all tests executed are documented with protocols containing enough information to demonstrate the performance status of the equipment. These protocols shall be signed by the responsible medical physicist, who shall ensure that they comply with this recommendation.

Finally, the execution of the checks described in this document requires the appropriate allocation of time and human resources, which directly affects the daily workload of the treatment machines. A heavy machine workload cannot be used as an argument to reduce or limit the control programme. The quality assurance procedures should be considered an integral part of the machine workload and the required time should be allocated within normal working hours. The work of medical physicists, or delegated co-workers, during evenings or weekends should be considered only in exceptional cases, or for urgent interventions.

Test frequencies are annually (a), monthly (m), or daily (d). Definitions for the abbreviations used in the text are provided at the end of the document.

2 Mechanical checks

2.1 Check of optical SSD indicators

Aim:
To check the SSD-light-indicator versus the mechanical distance indicator.

How to perform the test:
Compare the SSD-light-indicator with the mechanical distance indicator, (e.g. front pointer fixed to the gantry).

Suggested set-up conditions:
The test should be performed at three positions: at the reference SSD and also at both smaller and larger distances.

Frequency and tolerance:
m 2 mm

2.2 Collimator, gantry and treatment table rotation scales

Aim:
To check the correspondence between the readings at the treatment control panel or the display monitor, the mechanical scale readings (if used clinically) and the absolute position.

How to perform the test:

Collimator rotation: Rotate the gantry to approx. 90° or 270°. Align the light field edges at 0° collimator angle with the appropriate horizontal or vertical marks (e.g. set up with the help of a spirit level for absolute measurements) on the treatment room wall. Note the collimator reading at the treatment control panel or the display monitor and the reading on the mechanical scale on the treatment head. Repeat the above at 90° and 270° collimator angle.

Gantry rotation: Rotate gantry to 0°, 90°, 180° and 270° using a spirit level. Note readings from the treatment control panel or the display monitor as well as the mechanical readings.

Table rotation: Set the collimator angle to absolute 0° according to the procedure described above and rotate gantry to 0°. Align the front of the table top - at table angle 0° - to the light field edge. Note readings from the treatment control panel or the display monitor and compare to the mechanical readings, if existing. Align a graph paper to the cross hair cursor and rotate the table to 90° and 270° and note the readings.

Frequency and tolerance:

		Absolute measurement
Collimator rotation	m	0.5°
Gantry rotation	m	0.5°
Table rotation	m	0.5°

2.3 Treatment table movement scales

Aim:
To check the accuracy and linearity of the treatment table lateral, longitudinal and vertical motion scales.

How to perform the test:
The table height should be adjusted so that the table top intersects the isocenter and this table height should read zero. The table should be set to the zero position in the lateral and longitudinal directions. It is then moved a defined distance in each of the orthogonal directions and the displacement of the

table should be measured with a ruler and checked against the table lateral, longitudinal and vertical readouts.

Frequency and tolerance:
m 2 mm

2.4 Treatment table top deflection under load

Aim:
To assess the sagging of the treatment table top under load over the duration of a representative treatment time (20 min).

How to perform the test:
Position the tabletop longitudinal to a clinically relevant position and load it with an average expected load (~80kg), with the weight spread symmetrically on either side of the isocenter. Adjust the surface of the tabletop to isocenter and note the vertical reading. After approximately 20 minutes, measure the difference between the tabletop surface and the isocenter height.

Frequency and tolerance:
a 2 mm deflection after 20 minutes under load

2.5 Light /radiation field coincidence

Aim:
To test the congruence of the radiation and light field at various gantry angles and all photon beam energies.

How to perform the test:
A film is placed perpendicular to the beam central axis at the isocenter. The edges of the light field and the crosshair are marked before the film is exposed. The difference between the edges of the light and radiation fields can be checked on this film, for example using a densitometer to establish the radiation field edge. Alternatively, this test can be performed with any kind of appropriate equipment.
This test is normally performed at a gantry angle of 0°, but possible movement of the light source as the gantry is rotated could be detected if the congruence of the radiation and light fields is checked at other angles. At least two field sizes (e.g. 10x10 cm^2 and 20x20 cm^2) at gantry angle 0° and at least one field size at gantry angles different from 0° (e.g. 90°, 270°) should be tested for each energy used clinically. This check should also be carried out at an additional SSD (other than the reference SSD) at one gantry angle and one field size.

Frequency and tolerance:
m Gantry angle 0°, 2 mm between field edges and between the field centre and crosshair indication of field centre
a Gantry angle ≠ 0°, 2 mm between field edges
Gantry angle 0°, at an additional SSD, 2 mm between field edges

2.6 Mechanical isocenter check

A general note on checks of the isocenter position: Checking the mechanical isocenter position, the radiation isocenter position and the optical indication of the isocenter and their relative alignment is a complex procedure with many aspects being inter-related. Thus, it does not lend itself easily to independent checks of the separate components as appears to be implied by tests listed below. In practice, additional tests like e.g. Winston Lutz might be performed [19, 20].

2.6.1 Rotation axis of the collimator

Aim:
To verify that the crosshairs are aligned with the collimator rotation axis.

How to perform the test:
This test should be performed prior to other tests of the mechanical isocenter, which are based on the assumption of correctly aligned crosshairs. With the gantry and treatment table angles set to zero, and using graph paper on the treatment table, the crosshair position is marked as the collimator is rotated to 0°, 90° and 270° in order to establish the maximum deviation with collimator rotation. The test should be performed at two distances (one of which should be at the SID).

Frequency and tolerance:
m 2 mm (all points should be located within a 2 mm diameter circle)

2.6.2 Treatment table rotation

Aim:

To verify that the crosshairs are aligned to the table rotation axis

How to perform the test:
With the gantry and collimator angles set to zero, and using graph paper on the treatment table, the crosshair position should be marked as the table is rotated to 0°, 90° and 270° such as to establish the maximum deviation.

Frequency and tolerance:
m 2 mm (all points should located within a 2 mm diameter circle)

2.6.3 Rotation axis of the gantry

Aim:
To verify that the gantry rotation axis lies within the isocenter sphere.

How to perform the test:
The position of an isocenter indicator (either the crosshairs, or an indicator attached to the gantry), is measured relative to a fixed point marking the isocenter position, as the gantry is rotated.
For example: a plate mounted such that it can be rotated about a cross marked on its surface, is set so that the cross is at the indicated isocenter distance and aligned with the crosshairs. The alignment of the crosshairs to the marked cross on the plate is checked as the gantry is rotated. A variety of such tools is commercially available.
An alternative method is to use a sharp pointer attached to the gantry (in the same manner as the front pointer). This is aligned on the collimator rotation axis and with the tip at the isocenter distance. A second rigid pointer is mounted on the treatment table or the floor so as to mark the isocenter. The deviation of the tips of the two pointers is measured as the gantry is rotated.

Frequency and tolerance:
m 2 mm (all points should be located within a 2 mm diameter sphere containing the isocenter.)

2.7 Radiation isocenter check

The following two tests should be performed independently for all clinically used photon beams.

2.7.1 'Star film'

Aim:
To confirm that, in the plane of the gantry rotation, the radiation beam axes intersect within a 2 mm circle and that the radiation isocenter is coincident with the mechanical isocenter.

How to perform the test:
A film is placed vertically in the plane of gantry rotation. The indicated isocenter position should be marked on the film. The film is exposed at different gantry angles, with the narrowest possible field setting. The image on the film will be a star shape. The intersection of all beams marks the radiation isocenter established in the plane of the film.

Frequency and tolerance:

a 2 mm (all beams should be centered within a 2 mm diameter circle containing the marked mechanical isocenter.)

2.7.2 Alignment of opposing fields

Aim:

As the star film is only sensitive to errors in the plane of the gantry rotation, this test is suggested to detect errors in the perpendicular direction.

How to perform the test:

A film is set up and marked at the field centre and field edges with the gantry at 0° in the same way as for the light/radiation coincidence test (2.5). Then the film is exposed with the gantry at 180°. By comparing this film with that taken for test 2.5, any relative movement of the radiation fields and hence the radiation isocenter can be detected.

Frequency and tolerance:

a 2 mm

2.8 Laser alignment

Aim:

To check that all lasers correctly indicate the isocenter and that opposing lasers are congruent.

How to perform the test:

Indication of the isocenter:

A rotatable plate is adjusted in such a way that a point marked on its rotation axis is coincident with the light field crosshair at SAD. It is checked that the lateral and longitudinal lasers are coincident with this mark.

Congruence of lasers:

A piece of paper is put into the lateral laser beam at a distance further than 20 cm from the isocenter. The maximum deviation between the projections of the right and the left lateral lasers is recorded. The projection of the sagittal laser is compared to a reference mark, for example on the floor, (that is made at the time of acceptance of the laser system).

Brief daily check:

This should ensure that the lasers correctly indicate the isocenter, either using the method described above or by checking that the lasers coincide with appropriate marks made on the opposing walls.

Frequency and tolerance:

d 2 mm (distance between laser and indication of the isocenter)

m 1 mm (distance between laser and indication of the isocenter and congruence of the lasers. Note that for the congruence the tolerance is valid for deviations recorded at a distance of at least 20 cm from the isocenter).

2.9 Field size indicators

Aim:

To check that the field size indicator agrees with the measured field size.

How to perform the test:

The size of the light field or the radiation field is measured at the reference SSD in a plane perpendicular to the central axis. The chosen field size should be collimated starting from a larger field size as well as starting from a smaller field size. The width and length of the light field should be measured at the centre of the field. The measured field size is compared with the numerical field size indication. At least three different field sizes should be checked. For independent collimators it may be preferred to check predefined collimator settings against the measured collimator position for each jaw independently. The linearity of the scale is checked annually. The maximum over-travel as well as the maximum field size should be checked for each of the jaws.

If the light field is used clinically for electrons, then these checks should also be performed for electron fields.

Brief daily check:
One field size should be checked daily to ensure the integrity of the field size indicators

Frequency and tolerance:
d 2 mm for field size

m 2 mm for field size and over-travel

a check of linearity, 2 mm over the range of field sizes

2.10 Non-divergent asymmetric field check

Aim:
To check the overlap or gap at the junction of non-divergent asymmetric fields for various gantry angles.

How to perform the test:
At three different gantry angles (0°, 90° and 270°) a film or any other detector may be exposed four times in succession, with the four field quadrants, by setting the opposing jaws to the zero position.
In case of film, the crosshair is marked before the film is exposed. The maximum and minimum junction dose (ignoring the central axis region where all four fields abut) should be determined e.g. using a densitometer in case of films.

Frequency and tolerance:
m 2 mm overlap

For a penumbra fall-off of 10% per mm (80-20% penumbra width of 6 mm),this equates to a minimum/maximum junction dose of between 80% and 120% of the nominal dose.

3 Radiation Checks: X-Rays

3.1 Beam Output: definitive calibration, routine beam output check, constancy check

Aim:
To verify the machine output and the dose monitor calibration.

How to perform the test:
Definitive calibration:
This should be carried out annually for all available beam qualities following the procedures described in the SSRMP Recommendations No. 8 [10].
Routine beam output check using a recommended dosimeter:
This should be carried out for all available beam qualities using one of the dosimeters suggested in the appropriate SSRMP recommendations [10], or with a similar dosimeter and under similar conditions. However, a solid water-equivalent phantom may be used to replace the water phantom, with a hole drilled at a suitable depth, (e.g. 10 cm).
Brief beam output constancy check:
A variety of devices may be used, diodes, ionisation chambers, or one of the purpose built daily check dosimeters. In any case, the dosimetry system used for this check shall be different from the one used for the *Routine beam output check* described above. A measurement for all beam qualities used clinically is made under daily check conditions and is compared against the reference value established at the time of a calibration measurement.

Suggested set-up conditions:
10 x 10 cm^2 field, SDD = 100 cm or SSD = 100 cm, $d \geq d_{max}$

It is important to regularly check the constancy of the dosimeter systems used for the routine and definitive output checks against a reference measurement. This should be carried out with a check source at least every six months, or more frequently depending on the stability of the device.

Frequency and tolerance:

a	1%	Definitive calibration (relative to an internal reference value based on METAS calibration)
m	2%	Routine beam output check using a recommended dosimeter
d	3%	Brief beam output constancy check

3.2 Output constancy with gantry angle

Aim:
To verify the stability of the machine output with gantry angle.

How to perform the test:
The machine output should be checked at different gantry angles for each beam quality. An ionisation chamber with build-up cap can be placed at the isocenter, or a dosimeter may be attached to the gantry along the beam axis. The measured values should be compared with the value at the gantry angle used for the machine calibration.

Suggested set-up conditions:
10 x 10 cm^2 field, SDD = 100 cm, $d \geq d_{max}$, gantry angles 0°, 90°, 180° and 270°

Frequency and tolerance:
a 1%

3.3 Output constancy with dose rate

Aim:
To verify machine output constancy at different dose rates.

How to perform the test:
The beam output should be checked for each dose rate used clinically. Measurements should be compared with the output at the standard dose rate.

Suggested set-up conditions:
As for a routine beam output check.

Frequency and tolerance:
a 1%

3.4 Linearity of the dosimetry system

Aim:
To verify that the dose delivered per monitor unit is constant, i.e. is independent of the number of monitor units given. (The start-up and the end errors are checked at the same time).

How to perform the test:
The dose delivered per monitor unit should be verified, for all photon energies clinically used, for a range of monitor units. For example: minimum MU used clinically, MU setting leading to 0.2 Gy, 0.5 Gy, 1 Gy, 2 Gy, 4 Gy and maximum MU used clinically.

Suggested set-up conditions:
As for a routine beam output check.

Frequency and tolerance:
a 1%

3.5 Output factors

Aim:
To verify that the output factors (machine output variation with field size), are in agreement with the values determined at the time of commissioning the machine.

How to perform the test:
Output factor measurements should be made in a water tank at d_{ref} for a few square and rectangular fields. The ratio of the dose at d_{ref} for the given field and the reference 10 x 10 cm^2 field gives the output factor.

Suggested set-up conditions:
Field sizes: 6 x 6 cm^2, 10 x 10 cm^2, 20 x 20 cm^2 and maximum, also 6 x 30 cm^2 and 30 x 6 cm^2, SDD = 100 cm, d = d_{ref}.

Frequency and tolerance:
a 1%

3.6 Tray transmission factors

Aim:
To verify the beam transmission through the tray.

How to perform the test:
The ratio of the ionisation chamber reading measured with the shadow tray in the beam to that without the tray is calculated and compared with the reference value. For a tray with holes, a weighted average of the transmission factor should be calculated taking the relative areas of holes and solid tray into account.

Suggested set-up conditions:
10 x 10 cm^2 field, SDD = 100 cm, d = d_{ref}.

Frequency and tolerance:
a 1%

3.7 Wedge factors (mechanical wedges)

Aim:
To verify the wedge transmission ratio on the central axis.

How to perform the test:
The dose should be measured in a wedged beam and also in an open field under the same conditions and then the ratio of the two doses is calculated. When making the wedged field dose measurement using an ionisation chamber the axis should be in the unwedged direction. Measurements should be made with the collimators rotated through 180^o and for both wedge directions (e.g. “in” and “out”) if more than one direction is possible, and then the mean value is used to calculate the wedge factor. Measurements must be compared to baseline data.

Suggested set-up conditions:
10 x 10 cm^2 field, SDD = 100 cm, d = d_{ref}.

Frequency and tolerance:
a 1% (for mechanical wedges)
m 1% (for motorised wedges)

3.8 Wedge factor constancy with gantry angle (mechanical wedges)

Aim:
To verify that any backlash in the wedge position is minimal.

How to perform the test:
The checks should be carried out as described in paragraph 3.7, but also with the gantry at 90° and 270° and the collimator in both directions. The values measured should be compared with the value at the reference gantry angle.

Suggested set-up conditions:
10 x 10 cm^2 field, SDD = 100 cm, d = d_{ref}.

Frequency and tolerance:
a 1%

3.9 Dynamic wedge factors

Aim:
To verify the dynamic wedge 'transmission' ratio on the central axis.

How to perform the test:
Wedge factor constancy check:
The dose should be measured in a wedged beam and also in an open field under the same conditions and then the ratio of the two doses is calculated. When making the wedged field dose measurement using an ionisation chamber the axis should be in the unwedged direction. Measurements should be made with the collimators rotated through 180^o and for both wedge directions (e.g. "in" and "out") if more than one direction is possible, and then the mean value is used to calculate the wedge factor. Measurements must be compared to baseline data.
Brief beam output constancy check:
A variety of devices may be used, diodes, ionisation chambers, or one of the purpose built daily check dosimeters.

Suggested set-up conditions:
The field size should be as large as possible. For the brief output constancy check, wedges can be checked on a rotational basis, with at least one wedge checked daily and all wedges checked at least once per month.

Frequency and tolerance:
a 1% (wedge factor for all wedges)
d 3% brief output constancy check

3.10 Dynamic wedge profiles

Aim:
To verify the dynamic wedge profile.

How to perform the test:
An air-scanner, film, EPID or 2D-array may be used. The profile should be measured in the direction of the dynamic wedge for the largest possible field size in at least 3 points including the central axis.

Suggested set-up conditions:
The field size should be as large as possible. The gantry angle should be set to 0°. Different wedge angles and/or orientations should be checked alternately for each beam energy used clinically.

Frequency and tolerance:
m 2% (maximal deviation relative to central axis dose for each position measured)

3.11 Interrupted dynamic wedge exposures

Aim:
To verify the dynamic wedge dose profile resulting from an interrupted dynamic wedge irradiation.

How to perform the test:
Same setup as in 3.10 should be used. During irradiation in the "clinical mode", the beam is switched off and on and the resulting dose profile is compared to the baseline for an uninterrupted exposure, i.e. as in 3.10.

Suggested set-up conditions:
The field size should be as large as possible (the same as used in 3.10).

Frequency and tolerance:

m	2%	of dose measured on central axis of uninterrupted profile

3.12 Dynamic wedge factor variation with gantry angle

Aim:
The wedge factor should be measured at different gantry angles to ensure that gravitational effects are insignificant.

How to perform the test:
The checks should be carried out as described in paragraph 3.10, but also with the gantry at 90° and 270° and the collimator in both directions. The values measured should be compared with the value at the reference gantry angle (0°).

Suggested set-up conditions:
This test should be performed for the largest dynamic wedge angle at gantry angles 0°, 90° and 270°.

Frequency and tolerance:

a	1%

3.13 Beam energy

Aim:
To verify, through the beam penetration, the stability of the incoming photon spectrum.

How to perform the test:
Extensive check:
Perform a depth dose measurement on the central axis in a water phantom. Determine the depth of d_{max}. Measurement of $TPR_{20/10}$ (or, alternatively, the J_{10}/J_{20} ratio,) in a water phantom, or solid phantom.
Brief check:
Measure the dose at two different depths in a (solid) phantom (e.g. at 10 and 20 cm depth or 5 and 15 cm) and compute the ratio between the two readings.
Devices: ion chamber, diode, diamond detector.

Suggested set-up conditions:
10 x 10 cm^2 field, SSD = reference for calibration or 100 cm, SDD = 100 cm for $TPR_{20/10}$.

Frequency and tolerance:

a	1%	expected $TPR_{20/10}$ (or J_{10}/J_{20})
a	1%	of dose at dmax (for all depths greater than d_{max})
a	2 mm	expected d_{max}
m	1%	expected ratio of dose at two depths

3.14 Dose profiles at reference gantry position

Aim:
A suitably flattened beam is established at commissioning, whereafter quality control checks should ensure that the dose profile retains the same shape as for the beam data measurements.

How to perform the test:
Extensive check:
Measure dose profiles along the major beam axes for all beam qualities. Compare the dose profiles with the reference dose profiles.

Brief check:
'In phantom' or 'in air' profiles may be measured. The relative dose can be measured at a minimum of 5 points, one on the central axis and two on each of the major field axes (paired dose points located symmetrically about the central axis). Compare the profiles with the reference profiles, alternatively, evaluate the flatness and symmetry parameters.

Suggested set-up conditions:
Extensive check:
Field sizes: 5 x 5 cm^2, 10 x 10 cm^2, 20 x 20 cm^2 and maximum field size, SDD = 100 cm, d = d_{ref}, gantry 0°.
Devices: ion chamber, diamond detector, diode or linear array in a water phantom.
Brief check:
Field size: One field size, as limited by the linac or the measuring device used.
Devices: ion chamber, diode, linear array in a water phantom, or film or 2D-array in a slab phantom. Measurements could be performed in air with an ionization chamber or diode attached to an air scanner, or with an EPID.

Frequency and tolerance:

m	3%	*Brief check*: deviation from baseline measurements (within the flattened area)
a	2%	*Extensive check*: deviation from profiles measured at commissioning (within the flattened area)

3.15 Dose profile constancy with gantry angle

Aim:
To verify the stability of the dose across a homogeneous radiation field at different gantry angles with respect to that at the reference gantry angle.

How to perform the test:
Measure profiles along the major beam axes at different gantry positions for all energies. Evaluate the variations in the profile with respect to the baseline measurements at the reference gantry angle.
Devices: ion chamber, diode, linear array attached to an air scanner, or film or 2D-array in a slab phantom, or EPID, or devices measuring the dose at the centre and two (four) symmetric points on the beam profiles.

Suggested set-up conditions:
Field size: maximum field size (as limited by the linac or the measuring device used).
SDD = 100 cm, d = d_{ref} (or d_{max} if 'in air' measurements are performed), gantry angles 0°, 90°, 180° and 270°.

Frequency and tolerance:

a	2%	deviation from baseline measurements (within the flattened area)

3.16 Gantry rotation speed / MU delivered per unit angle

Aim:
To check that the MU delivered per unit angle interval is correct. (The dose rate does not necessarily remain constant during the rotation, however, the gantry rotation speed should be altered to compensate for this). It is only necessary to perform this test if rotational irradiation is clinically implemented.

How to perform the test:
Check that the MU delivered during gantry rotation is as expected for various angle intervals throughout 360°. Alternatively, a film may be exposed around a cylindrical phantom, producing a resultant uniform dose distribution.

Frequency and tolerance:
m 2%

3.17 Radiation survey

Aim:
Check that the ambient dose equivalent at relevant points around the treatment areas, (e.g. at the console, by the treatment room doors), lies within the limits specified at acceptance.

Frequency and tolerance:
Must be re-measured when structural changes are made and results have to be compared to the situation at acceptance.

4 Multileaf collimator (MLC)

The tests described below are intended for non-modulated techniques. For modulated techniques, it is recommended to refer to the Recommendations No. 15 of SSRMP 2007 [21].

4.1 Leaf position accuracy

Aim:
To check the leaf position accuracy and the alignment of the individual leaves relative to one another.

How to perform the test:
Use a film/EPID to perform a matched segment or “picket fence” test, e.g. several abutting long rectangular MLC fields, for gantry angles 0°, 90°, 270° and 180°.

Frequency and tolerance:
m 1 mm per leaf (at different cardinal gantry angles on a rotational basis)

4.2 Leakage between leaves

Aim:
To check the radiation leakage between the leaves.

How to perform the test:
Expose a detector with the MLC set to a long rectangular field (for which the long field edges are perpendicular to the direction of leaf movement). Measure the transmission between the leaves

Frequency and tolerance:
a max transmission 5% of the unblocked central axis dose

5 Radiation checks: Electrons

5.1 Beam Output: definitive calibration, routine beam output check, constancy check

Aim:
To verify the machine output and the dose monitor calibration.

How to perform the test:
Definitive calibration:
This should be carried out annually for each electron energy following the procedures described in the SSRMP Recommendations No. 10 [11].
Routine beam output check using a recommended dosimeter:
This should be carried out for each electron energy using one of the dosimeters recommended by the relevant SSRMP recommendations [11], or a similar dosimeter and under similar conditions. However, a solid water equivalent phantom may be used to replace the water phantom, with a hole drilled at a depth suitable for each electron energy (e.g. d_{max}). A cylindrical ion chamber may be used instead of a parallel-plate chamber if the set-up conditions are reproducible.

Brief beam output constancy check:
A variety of devices may be used, diodes, ionisation chambers, or one of the purpose designed daily check dosimeters. In any case, the dosimetry system used for this check must be different from the one used for the *Routine beam output check* described above. A measurement is made for all electron energies clinically in use, under daily check conditions, and is compared to the reference value established at the time of a calibration measurement.

Suggested set-up conditions:
Applicator size 10 x 10cm^2 or greater, SSD = 100 cm, d = d_{max}.
It is important to regularly check the constancy of the dosimeter systems used for the routine and definitive output checks against a reference measurement. This should be carried out with a check source at least every six months, or more frequently depending on the stability of the device.

Frequency and tolerance:

a	1%	Definitive calibration (relative to an internal reference value based on METAS calibration)
m	2%	Routine beam output check using a recommended dosimeter
d	3%	Brief beam output constancy check

5.2 Output constancy with gantry angle

Aim: to verify the stability of the machine output with gantry angle.

How to perform the test:
The machine output should be checked at different gantry angles for each electron energy. An ionisation chamber with build-up cap can be placed at the isocenter, or a dosimeter may be attached to the gantry along the beam axis. The values measured should be compared with the value at the gantry angle used for the machine calibration.

Suggested set-up conditions:
Applicator size 10 x10cm^2 or greater, SDD = 100 cm, d = d_{max}, gantry angles 0°, 90°, 180° and 270°.

Frequency and tolerance:
a 1%

5.3 Output constancy with dose rate

Aim:
To verify machine output constancy at different dose rates.

How to perform the test:
The beam output should be checked for each dose rate used clinically. Measurements should be compared with the output at the standard dose rate.

Suggested set-up conditions:
As for a routine beam output check.

Frequency and tolerance:
a 1%

5.4 Linearity of the dosimetry system

Aim:
To verify that the dose delivered per monitor unit is constant, i.e. is independent of the number of monitor units given. (The start-up and the end errors are checked at the same time).

How to perform the test:
The dose delivered per monitor unit should be verified, for all electron energies clinically used, for a range of monitor units. For example: minimum MU used clinically, MU setting leading to 0.2 Gy, 0.5 Gy, 1 Gy, 2 Gy, 4 Gy and maximum MU used clinically.

Suggested set-up conditions:
As for a routine beam output check.

Frequency and tolerance:
a 1%

5.5 Output factors for different applicators

Aim:
To verify that the output factors (machine output variation with different applicators using standard inserts) are in agreement with the values determined at the time of commissioning the machine.

How to perform the test:
Measurements should be made in a water tank or water equivalent phantom at d_{max} for all applicators and all electron energies. The ratio of the dose at d_{max} for the given applicator and the 'standard' applicator gives the output factor.

Suggested set-up conditions:
All applicators, SSD = 100 cm, d = d_{max}. If adjustable applicators are available, a set of at least 5 field sizes, representative of those used clinically, should be used for tests (e.g. 5 x 5 cm^2, 10 x 10 cm^2, 15 x 15 cm^2, 20 x 20 cm^2, maximum allowed).

Frequency and tolerance:
a 1%

5.6 Beam energy

Aim:
To verify the stability of the electron beam energy by measurement of the beam penetration.

How to perform the test:
Extensive check:
Perform a depth dose measurement on the central axis in a water phantom. Determine the shift in the position of, for example, the d_{80} or d_{50} values established at commissioning.
Additionally, determine the x-ray contamination and its variation relative to the commissioning value.

Brief check:
Measure the dose, or ionisation, at two different depths in a (solid) phantom (ideally one of the depths should be close to the maximum ionisation depth and the other on the descending part of the curve). The deviation of the measured ratio from the baseline measurement should be converted into a range shift.
Devices: ion chamber, diode, diamond detector.

Suggested set-up conditions:
Applicator size 10x10 cm^2 or 15 x 15 cm^2, SSD = 100 cm, gantry angle 0°, all electron energies.

Frequency and tolerance:

a	1 mm	for extensive check
a	1%	of expected X-ray contamination
m	1 mm	

5.7 Dose profiles at reference gantry angle

Aim:
A suitably flattened beam is established at commissioning, whereafter quality control checks should ensure that the dose profile retains the same shape as for the beam data measurements.

How to perform the test:
Extensive check:
Measure dose profiles along the major beam axes for all beam qualities.
Compare the dose profiles with the reference dose profiles.
Brief check:
'In phantom' or 'in air' profiles may be measured. The relative dose can be measured at a minimum of 5 points, one on the central axis and two on each of the major field axes (paired dose points located symmetrically about the central axis). Compare the profiles with the reference profiles, alternatively, evaluate the flatness and symmetry parameters.

Suggested set-up conditions:
Extensive check:
Field sizes: 5 x 5 cm^2, 10 x 10 cm^2, 20 x 20 cm^2 and maximum field size, SDD = 100 cm, d = d_{ref}, gantry 0°.
Devices: ion chamber, diamond detector, diode or linear array in a water phantom.
Brief check:
Field sizes: 10 x 10 cm^2 or 15 x 15 cm^2 and maximum field size (as limited by the linac or the measuring device used).
Devices: ion chamber, diode, linear array in a water phantom, or film or 2D-array in a slab phantom. Measurements could be performed in air with an ion chamber or diode attached to an air scanner, or with an EPID.

Frequency and tolerance:

m	3%	Brief check: deviation from baseline measurements (within the flattened area)
a	2%	Extensive check: deviation from profiles measured at commissioning (within the flattened area)

5.8 Dose profile constancy with gantry angle

Aim:
To verify the stability of the dose across a homogeneous radiation field at different gantry angles with respect to that at the reference gantry angle.

How to perform the test:
Measure profiles along the major beam axes at different gantry positions for all energies. Evaluate the variations in the profile with respect to the baseline measurements at the reference gantry angle.

Devices: ion chamber, diode, linear array attached to an air scanner, film or 2D-array in a slab phantom, EPID, or devices measuring the dose at the centre and two (four) symmetric points on the beam profiles.

Suggested set-up conditions:
Field size: maximum field size (as limited by the linac or the measuring device used).
SDD = 100 cm, d = d_{ref} (or d_{max} if 'in air' measurements are performed), gantry angles 0°, 90°, 180° and 270°.

Frequency and tolerance:
a 2% deviation from baseline measurements (within the flattened area)

6 Checks relating to the mechanical integrity and safety of the machine

Since practical aspects of safety checks tend to vary from one centre to another, depending on the installed devices, the sub-paragraph "how to perform the test" is skipped for this section. Tests to be performed on several devices serving the same function (e.g. emergency off switches) could be performed on a rotational basis provided that all are tested at least once per year.

6.1 Room entrance interlock

Aim: To ensure that in the case of a person attempting to enter the treatment room whilst the treatment is running, the beam is switched off.

Frequency and tolerance:
d functional

6.2 Manual door opening

Aim:
To ensure that the treatment room door can be opened manually in any instance, for example in case of power failure.

Frequency and tolerance:
a functional

6.3 Audio video monitor

Aim:
To ensure that the systems allowing audio and video contact with the patient in the treatment room are functioning correctly.

Frequency and tolerance:
d functional

6.4 Beam on indicators

Aim:
To ensure that the beam on indicator that is visible from outside the treatment room, lights during irradiation.

Frequency and tolerance:
d functional

6.5 Beam terminate switch

Aim:
To check that the beam terminate button/switch at the treatment console is functional.

Frequency and tolerance:
d functional

6.6 Emergency off switches

Aim:
To check that the linear accelerator is switched off, on pushing one of the emergency off switches.

Frequency and tolerance:
m functional (in rotation with every switch checked at least once per year)

6.7 Touch guards

Aim:
To ensure that activation of any patient collision touch guard causes the machine movement to be halted.

Frequency and tolerance:
m functional

6.8 Table locking brakes

Aim:
To check the correct function of the table locking brakes.

Frequency and tolerance:
m functional

6.9 Deadman's switches

Aim:
To check that releasing any deadman's switch disables the machine movement being controlled by the operator.

Frequency and tolerance:
m functional

6.10 Accessory (tray and wedge) interlocks

Aim:
To check that the interlock correctly indicates if an accessory (block tray or wedge) is in place and in the case of a machine with multiple mechanical wedges, which wedge is in place and in which orientation. The machine should not run if the interlock indication does not match the selection at the console.

Frequency and tolerance:
m functional

6.11 Trays, wedges, blocks and electron applicators

Aim:
Check that these are fixed correctly, such that they cannot fall off, and check the correct function of electron applicator collision touch guards.

Frequency and tolerance:
m functional
(The electron applicators may be checked on a rotational basis)

6.12 Backup dose monitor check

Aim:
Check that the backup monitor can switch off the beam.

Frequency and tolerance:
m functional

6.13 Timer function

Aim:
Check that the timer can switch off the beam.

Frequency and tolerance:
m functional

6.14 Backup couch lowering system in case of power failure

Aim:
Check the function of any special equipment used to retrieve the patient in case of power failure

(emergency couch lowering system and emergency movement of the gantry).

Frequency and tolerance:
m functional (monthly in combination with the emergency off switches)

7 Special treatment modalities

Special treatment techniques are being clinically implemented in many Swiss centres, they include for example:

- Total/half body photon irradiation
- Total skin electron irradiation
- Electron arc therapy
- Intra-operative radiotherapy
- Stereotactic radiosurgery or radiotherapy (cranial and body)
- Intensity Modulated Radiation Therapy (IMRT)
- Dynamic MLC arc therapy
- Volumetric Modulated Arc Therapy (VMAT)
- Gating (amplitude gating, phase gating, breath-hold gating)
- Fan beam therapy

All these techniques require dedicated quality assurance procedures, which are considered beyond the scope of the present recommendations. Dedicated SSRMP recommendations will cover these aspects of accelerator usage for patient treatment. In the meantime, specific quality assurance protocols are left to the responsibility of local medical physicists who should consider other international recommendations.

8 External dosimetry audit

At the time of commissioning, before the irradiation of the first patient, the beam calibration has to be checked by an external beam dosimetry audit.

In years when the SSRMP intercomparison is carried out, all centres must participate in the SSRMP intercomparison (or equivalent).

9 Tables: frequencies and tolerances

Table 1: Tests ordered by contents

Ref. Test	Frequency	Tolerance
2 Mechanical Checks		
2.1 Check of optical SSD indicators	m	2 mm
2.2 Rotation scales:		
Collimator rotation	m	0.5º
Gantry rotation	m	0.5º
Treatment table rotation	m	0.5º
2.3 Treatment table movement scales	m	2 mm
2.4 Treatment table top deflection under load	a	2 mm
2.5 Light and radiation field coincidence		
at the reference SSD and gantry angle 0°	m	2 mm
at an additional SSD and different gantry angles	a	2 mm
2.6 Mechanical isocenter check		
Rotation axis of collimator	m	2 mm
Treatment table rotation	m	2 mm
Rotation axis of the gantry	m	2 mm
2.7 Radiation isocenter check		
Star film	a	2 mm
Alignment of opposing fields	a	2 mm
2.8 Laser alignment	m	1 mm
Brief check	d	2 mm
2.9 Field size indicators	m	2 mm
Brief check	d	2 mm
Linearity	a	2 mm
2.10 Non-divergent asymmetric field check	m	2 mm
3 Radiation Checks: X-rays		
3.1 Beam Output:		
Brief beam output constancy check	d	3 %
Beam output check using a recommended dosimeter	m	2 %
Definitive calibration	a	1 %
3.2 Output constancy with gantry angle	a	1 %

3.3 Output constancy with dose rate	a	1 %
3.4 Linearity of the dosimetry system	a	1 %
3.5 Output factors	a	1 %
3.6 Tray transmission factors	a	1 %
3.7 Wedge Factors (mechanical wedges):		
Manual mechanical wedges	a	1 %
Motorised mechanical wedges	m	1 %
3.8 Wedge Factor constancy with gantry angle	a	1 %
3.9 Dynamic wedge factors	a	1 %
Brief check (output)	d	3 %
3.10 Dynamic wedge profiles	m	2 %
3.11 Interrupted dynamic wedge exposures	m	2 %
3.12 Dynamic Wedge factor variation with gantry angle	a	1 %
3.13 Beam energy:		
Brief check: ratio of dose at two depths	m	1 %
$TPR_{20/10}$ (or J_{10}/J_{20})	a	1 %
Depth dose curve	a	1 %
Depth of d_{max}	a	2 mm
3.14 Dose profiles at reference gantry angle:		
Brief check	m	3 %
Extensive check	a	2 %
3.15 Dose profile constancy with gantry angle	a	2 %
3.16 Gantry rotation speed/MU delivered per unit angle interval	m	2 %
3.17 Radiation survey	After structural changes	-
4 Multileaf Collimator (MLC)		
4.1 Leaf position accuracy	m	1 mm
4.2 Leakage between the leaves	a	5 %
5 Radiation Checks: Electrons		
5.1 Beam Output:		
Brief beam output constancy check	d	3 %
Beam output check using a recommended dosimeter	m	2 %
Definitive calibration	a	1 %
5.2 Output constancy with gantry angle	a	1 %
5.3 Output constancy with dose rate	a	1 %
5.4 Linearity of the dosimetry system	a	1 %

5.5	Output factors for different applicators	a	1 %
5.6	Beam energy:		
	Brief check: ratio of dose at two depths	m	1 mm
	Depth dose curve	a	1 mm
	X-ray contamination	a	1 %
5.7	Dose profiles at reference gantry angle:		
	Brief check	m	3 %
	Extensive check	a	2 %
5.8	Dose profile constancy with gantry angle	a	2 %
6	**Checks relating to the mechanical integrity and safety of the machine**		
6.1	Room entrance interlock	d	functional
6.2	Manual door opening	a	functional
6.3	Audio video monitor	d	functional
6.4	Beam on indicators	d	functional
6.5	Beam terminate switch	d	functional
6.6	Emergency off switches	m (in rotation)	functional
6.7	Touch guards	m	functional
6.8	Table locking brakes	m	functional
6.9	Deadman's switch	m	functional
6.10	Accessory (tray and wedge) interlocks	m	functional
6.11	Trays, wedges, blocks and electron applicators	m	functional
6.12	Backup dose monitor check	m	functional
6.13	Timer function		
	Switch off the beam	m	functional
6.14	Backup couch lowering system in case of power failure	m	functional
8	**External dosimetry audit**		
	External audit	commissioning	
	SSRMP intercomparison	a	

Table 2: Tests ordered by frequency

Test and frequency	Reference	Tolerance
Daily		
Room entrance interlock	6.1	functional
Audio video monitor	6.3	functional
Beam on indicators	6.4	functional
Beam terminate switch	6.5	functional
Laser alignment	2.8	2 mm
Field size indicators	2.9	2 mm
Beam Output: Brief beam output constancy check:		
Photons	3.1	3 %
Electrons	5.1	3 %
Dynamic wedge output	3.9	3 %
Monthly		
Emergency off switches (in rotation)	6.6	functional
Touch guards	6.7	functional
Table locking brakes	6.8	functional
Deadman's switch	6.9	functional
Accessory (tray and wedge) interlocks	6.10	functional
Trays, wedges, blocks and electron applicators	6.11	functional
Backup dose monitor check	6.12	functional
Timer function	6.13	functional
Backup couch lowering system in case of power failure	6.14	functional
Check of optical SSD indicators	2.1	2 mm
Rotation scales:		
Collimator	2.2	0.5 º
Table	2.2	0.5 º
Gantry	2.2	0.5 º
Treatment table movement scales	2.3	2 mm
Light and radiation field coincidence	2.5	2 mm
Mechanical isocenter check	2.6	2 mm
Laser alignment	2.8	1 mm
Field size indicators	2.9	2 mm
Non-divergent asymmetric field check	2.10	2 mm

Routine beam output check using a recommended dosimeter		
Photons	3.1	2 %
Electrons	5.1	2 %
Wedge factors (motorised wedges only)	3.7	1 %
Dynamic wedge profiles	3.10	2 %
Interrupted dynamic wedge exposures	3.11	2 %
Beam energy: Quick check, ratio of dose at two depths		
Photons	3.13	1 %
Electrons	5.6	1 mm
Dose profiles: Quick check		
Photons	3.14	3 %
Electrons	5.7	3 %
Gantry rotation speed / MU delivered per unit gantry angle	3.16	2 %
Leaf position accuracy	4.1	1 mm
Annually		
Treatment table top deflection under load	2.4	2 mm
Light and radiation field coincidence	2.5	2 mm
Radiation isocenter check		
Star film	2.7.1	2 mm
Alignment of opposing fields	2.7.2	2 mm
Field size indicator	2.9	2 mm
Beam output: Definitive calibration		
Photons	3.1	1 %
Electrons	5.1	1 %
Output constancy with gantry angle		
Photons	3.2	1 %
Electrons	5.2	1 %
Output constancy with dose rate		
Photons	3.3	1 %
Electrons	5.3	1 %
Linearity of the dosimetry system		
Photons	3.4	1 %
Electrons	5.4	1 %
Output factors for different field sizes		
Photons	3.5	1 %
Electrons (for different applicators)	5.5	1 %

Tray transmission factors	3.6	1 %
Wedge factors (mechanical wedges)	3.7	1 %
Wedge factor constancy with gantry angle (mechanical)	3.8	1 %
Dynamic wedge factor	3.9	1 %
Dynamic wedge factor variation with gantry angle	3.12	1 %
Beam energy photons:		
$TPR_{20/10}$ (or J_{10}/J_{20})	3.13	1 %
Depth dose	3.13	1 %
Depth of d_{max}	3.13	2 mm
Beam energy electrons:		
Depth dose curve	5.6	1 mm
X-ray contamination	5.6	1 %
Dose profiles: Extensive checks		
Photons	3.14	2 %
Electrons	5.7	2 %
Dose profile constancy with gantry angle		
Photons	3.15	2 %
Electrons	5.8	2 %
Radiation survey (only after structural changes)	3.17	-
Leakage between the MLC leaves	4.2	5% of the unblocked central axis dose
Manual door opening	6.2	Functional

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11 Definitions and Glossary

$TPR_{20/10}$: tissue phantom ratio between 20cm and 10cm depth.

J_{10}/J_{20}: ratio between ionisation at 10cm and 20cm depth in the same conditions.

d: measuring depth.

d_{max}: depth of the maximum dose.

d_{ref}: reference depth.

Field size: distance between the 50% level in profiles normalised to 100% at the beam central axis.

Flattened area: For photons the area inside the 80% of the field size along the main axes. For electrons the flattened area should be defined as the central 80% of the field width at the phantom surface.

Flatness:

- percentage dose difference (AAPM TG 45, IEC): $\left(\frac{P_{max} - P_{min}}{P_{max} + P_{min}}\right) \cdot 100$

- percentage dose ratio (IPEM81, IEC): $\left(\frac{P_{min}}{P_{max}}\right) \cdot 100$

SDD: Source to Detector Distance

SSD: Source to Surface Distance

SID: Source to Isocenter Distance

Symmetry: (AAPM, IPEM, DIN, IEC): $\max\left(\frac{D(x)}{D(-x)}\right) \cdot 100$

Isocenter: The definition of the term isocenter by the IEC is "the centre of the smallest sphere through which the axis of the radiation beams pass in all conditions".

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