Quality Control of Medical Linear Accelerators

Current practice and minimum requirements

NEDERLANDSE COMMISSIE VOOR STRALINGSDOSIMETRIE

Report 9 of the Netherlands Commission on Radiation Dosimetry

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Preface

At the end of 1995, the Netherlands Commission on Radiation Dosimetry (NCS) issued their report no. 8, entitled 'Kwaliteitscontrole van Medische Lineaire Versnellers, methoden voor kwaliteitscontrole, wenselijke toleranties en frequenties' (Quality Control of Medical Linear Accelerators, methods for quality control, desirable tolerances and frequencies). The main purpose of this report, which was written in Dutch, was to provide a description of methods available in The Netherlands for quality control procedures. With the financial support of the Dutch Ministry of Health, Welfare and Sports, a study was subsequently performed by colleagues from The Netherlands Cancer Institute in Amsterdam and the University Hospital in Utrecht to investigate to what extent these quality programmes are implemented in the various radiotherapy institutes. The present report fully complies with the aims of the NCS, notably participation in dosimetry standardisation and promotion of dosimetry intercomparisons, drafting of dosimetry protocols, collection and evaluation of physical data related to dosimetry.

QUALITY CONTROL OF MEDICAL LINEAR ACCELERATORS
CURRENT PRACTICE AND MINIMUM REQUIREMENTS

Prepared by a project group initiated by the Netherlands Society on Clinical Physics and supported by the Netherlands Commission on Radiation Dosimetry, the Netherlands Society on Radiotherapy, the Dutch Society for Radiographers, the University Hospital Utrecht and the Netherlands Cancer Institute and financially supported by the Ministry of Health, Welfare and Sports.

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Summary

An extensive questionnaire on QC procedures of medical electron accelerators was completed by all (21) radiotherapy institutions in The Netherlands with items related to safety systems, mechanical parameters, radiation protection, beam profiles, beam energy, absolute dosimetry, wedge filters, the dose monitor system and leakage radiation. Large variations in time spent on QC exist, especially for dual energy photon accelerators with several electron beam energies. This diversity is mainly due to differences in philosophy with regard to QC and the differences in resources and machine time available. Large variations in test frequencies and test methodologies have been observed. The data of the questionnaire were compared with recommendations given in national and international reports on QC of electron accelerators. From these recommendations and the results of the questionnaire a set of minimum guidelines for a QC programme has been established specific for the situation in The Netherlands.

Introduction

This document is a report describing the first results of the project 'Development and implementation of guidelines for quality control in radiotherapy in The Netherlands', initiated by the Netherlands Society on Clinical Physics (NVKF) and supported by the Netherlands Commission on Radiation Dosimetry (NCS), the Netherlands Society on Radiotherapy (NVRT), the Dutch Society for Radiographers (NVRL), the University Hospital Utrecht (AZU) and the Netherlands Cancer Institute (NKI) and financed by the ministry of Health, Welfare and Sports of the Dutch government. The principal goal of this project is to achieve a consensus in the different QC programmes and to recommend national guidelines on QC procedures in radiotherapy. Three different phases can be distinguished in this project:

- *phase 1* : development of guidelines for QC of medical electron accelerators;
- *phase 2* : development of guidelines for QC of simulators and CT scanners;
- *phase 3* : development of guidelines for QC of treatment planning systems.

The results of the first phase are described in the current report.

In The Netherlands there are 21 radiotherapy institutions. All these institutions have a quality assurance (QA) programme, to ensure the safe and efficacious application of radiation for treatment of cancer. One of the aspects of such a general programme is devoted to the quality control (QC) of megavoltage radiation equipment. Up to now each institution applies its own criteria for QC-programmes, guided by the many directives published on this subject. Because of the various guidelines employed and the differences in individual interpretation, a large variety of QC protocols is currently applied in The Netherlands.

The Netherlands Commission on Radiation Dosimetry recently published a comprehensive report on methods for QC of medical linear accelerators (NCS Report 8citeNCS8). This NCS report covers a large number of subjects, including an extensive description of test methods, test frequencies and tolerance levels and is meant to serve as a model for good clinical practice. The checks described in the report are not meant to be mandatory. Firstly, the report is very comprehensive, describing checks for a large variety of circumstances. Secondly, the given test frequencies and tolerance levels are to be considered as a suggestion and can therefore be adapted to the local situation by a responsible physicist. Thirdly, in order to test a certain parameter, more than one method can be suitable, making it difficult to impose one test method for all radiotherapy institutions. Consequently, a more differentiated set of regulations has to be set up. It is, however, desirable to draft guidelines that should be used in any institution in The Netherlands.

In the current report such a **minimum** set of parameters has been formulated to be checked regularly together with minimum test frequencies and action levels suitable for all radiotherapy institutions in The Netherlands. In formulating these, we were lead by QC protocols nowadays employed in The Netherlands and other reports existing on quality assurance for radiotherapy[1, 4, 6, 7, 8, 10, 11, 14, 18, 19].

Inter-institutional survey

In order to obtain insight in the currently employed QC protocols for electron accelerators in The Netherlands, a questionnaire has been sent to all 21 radiotherapy institutions. The questionnaire concerned methods, frequencies, time required for the tests, tolerance levels as well as the training of the personnel performing these measurements. The data published in this report are directly gathered from the 21 responses (100%). In each paragraph, these data are directly compared with the previously mentioned NCS report 8 and with national and international recommendations taken from the following reports on quality assurance for medical linear accelerators:

AAPM : Kutcher, G.J., Coia, L., Gillin, M. et al. Comprehensive QA for radiation oncology: Report of AAPM Radiation Therapy Committee Task Group 40. Med. Phys. 21: 581-618, 1994.

Brahme et al. : Brahme, A., Chavaudra, J., Landberg, T., McCullough, E., Nüsslin, F., Rawlinson, A., Svensson, G. and Svensson, H., Accuracy requirements and quality assurance of external beam therapy with photons and electrons. Supplementum 1 to Acta Oncologica, Stockholm, Sweden, 1988.

DIN : DIN-Standard 6847 part 5. Medizinische Electronenbeschleuniger-Anlagen; Konstanzprüfungen apparativer Qualitätsmerkmale. Beuth-Verlag, Berlin, 1986.

Johansson et al. : Johansson, K.-A., Sernbo, G., Van Dam, J. Quality control of megavoltage therapy units, Radiotherapy physics in practice, Oxford, United Kingdom, 1993.

IEC : International Electrotechnical Commission Technical Report 977. Medical electrical equipment. Medical electron accelerators in the range 1 MeV to 50 MeV - Guidelines for functional performance characteristics. International Electrotechnical Commission, Geneva, Switzerland, 1989.

IPSM : Institute of Physical Sciences in Medicine Report No. 54. Commissioning and Quality Assurance of Linear Accelerators. IPSM Publications, York, United Kingdom, 1988.

SFPH : Société Française des Physiciens d' Hôpital Publication 4. Quality control of electron accelerators for medical use, SFPH, Institut Curie, Paris, France, 1989.

The frequencies of checks of parameters described in these reports are recommended test frequencies, with the exception of the frequencies given in the DIN report, which should be regarded as minimum test frequencies. Hence, due to subsequent experience with a particular machine, the recommended frequencies can either be increased, if a parameter is found to vary over a short time period, or decreased if a parameter is found to be exceptionally stable.

Nationally recommended guidelines

From the answers on the questionnaire and the comparison with other reports, a set of **minimum** requirements with respect to type of test, test frequency and action level has been proposed, suitable for all radiotherapy institutions in The Netherlands. These minimum requirements strictly refer to the ordinary QC-programme and no suggestions are made concerning additional control after major repair. The requirements given in the current report, all responsible physicists were given the opportunity to respond to the various test frequencies and action levels published in a draft report. None of the responses however indicated that implication of the suggested guidelines would cause any serious difficulties concerning the execution of these guidelines.

Test frequencies

The minimum frequency of the different checks will mainly depend on:

- the likelihood of occurrence of a malfunction;

- the chances that if a malfunction occurs, this will not be noticed during normal treatment applications[1];
- the seriousness of the possible consequences of an unnoticed malfunction to patients and/or personnel;
- the likelihood of these consequences as a result of a malfunction.

Note that the complexity, cost or time of a specific check do not influence the minimum test frequency. This results in a relation between the probability of an undetected malfunction, the seriousness of the malfunction for the patient or personnel and the minimum test frequency as shown in Table 1. Distinction has been made between no direct serious harmful effects, possible harmful effects (malfunctions which could reduce the treatment effect) and direct serious harmful effects (like a missing target during a photon beam treatment). Certainly not all test parameters can easily be divided into the stated categories, but the information given in the table could well serve as a guide in establishing minimum test frequencies.

Table 1: Relation between the probability of an undetected malfunction, the seriousness of the malfunction for the patient or personnel and the minimum test frequency

	low probability of undetected malfunction	high probability of undetected malfunction
no direct serious harmful effects	low frequency (*annual*)	middle frequency (*monthly*)
possible harmful effects	middle frequency (*monthly*)	high frequency (*daily, weekly*)
direct serious harmful effects	permanent interlock systems	

The suggested test frequencies prescribed in this report should be regarded as a **minimum** and **not** as an **optimum**; so the test frequencies can only be adjusted in one direction, i.e.

[1]For example, the functioning of the audiovisual monitoring system is extremely important for the safety of the patient, but because failure of the system would be instantaneously noticed, appropriate actions can be taken immediately. So there is no explicit check of the functioning of the audiovisual monitoring system as part of the QC programme.

more frequent, by an individual institution. This is necessary when the stability of a system is suspect or when a specific patient treatment method demands a special accuracy.

Tolerance levels and action levels

Contrary to the concept of (minimum) test frequency, many different interpretations of *tolerance* level exist. The stated tolerance level sometimes represents just a guideline for acceptable deviations. In other cases, a tolerance level has a stricter character in the sense that actions are (immediately) required if a tolerance level has been exceeded. The values of the tolerance levels in NCS Report 8 should be considered as desirable during normal clinical use of a medical linear accelerator. In the reports of Brahme et al.[1] and Johansson et al.[10] the concept of tolerance level has a different meaning. Recording to their definition, the equipment is suitable for high quality radiation therapy, if a parameter is in the range below the tolerance level. In these cases no actions are required unless a series of measured values stays close to one tolerance level. Besides this tolerance level, an *action* level is defined in such a way that whenever an action level is reached, it is essential that appropriate actions are taken. From this point of view, tolerance levels are appropriate limits for performance specification and for acceptance testing procedures, while action levels might be regarded as more relevant values for use in ongoing quality control activities. As a consequence, 'tolerance levels' used in this report can have different interpretations, depending on the related references.

The limits presented in this report should be regarded as action levels as defined by Brahme et al. (see also Figure 1). However, some parameters are not easily and quickly corrected or repaired; some may even be almost impossible or very expensive to restore. In a very few occasions, it might be justified to use the radiation equipment clinically, even if an action level has been exceeded. Such a delicate decision can only be taken after careful consideration of the responsible clinical physicist, with the knowledge of the clinicians and radiographers. For example, curative treatments demand a high stability of the treatment table height, especially during lateral irradiation. If due to mechanical tolerances the table height cannot be adjusted within 1 cm, it still may be justified to perform palliative posterior-anterior or anterior-posterior treatments if no alternatives are present at all. The decision to clinically use a treatment unit, in spite of the fact that an action level has been exceeded, has to be discussed thoroughly and documented for every treatment method. Under these special circumstances the action level can no longer be considered as restrictive; i.e. since the clinical relevance of a parameter can differ considerably from one treatment to another, it is impossible to implement an action level as a mandatory minimum demand.

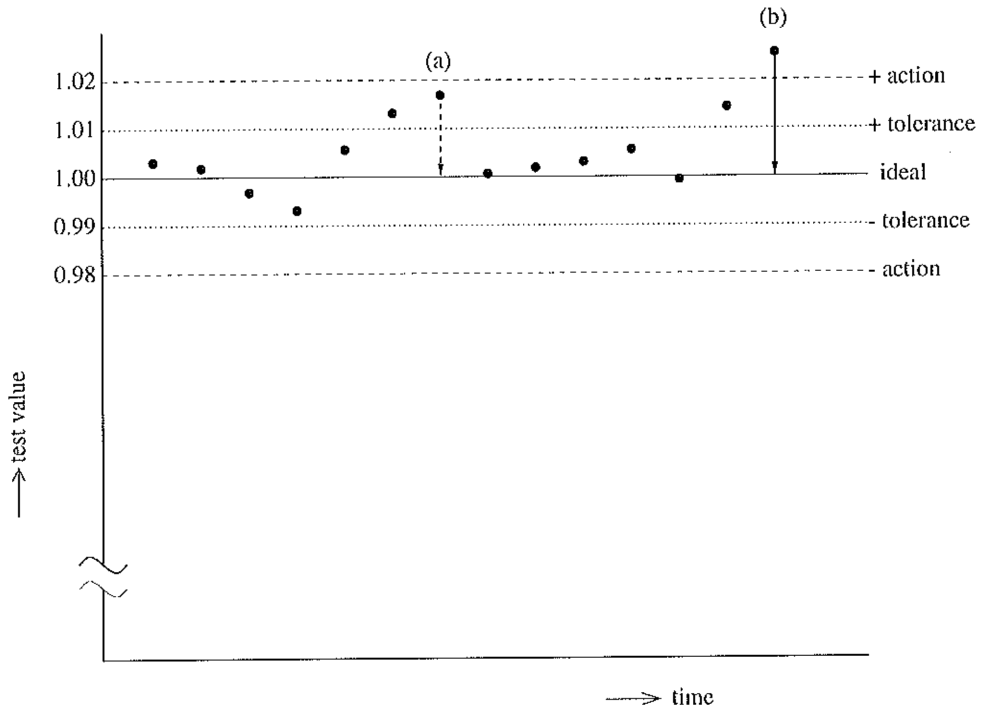


Figure 1: In this graph the definitions of tolerance and action level are shown, for an arbitrary parameter. In this example the tolerance level is set to 1% and the action level is set to 2%. The dots indicate the results of QC tests on a time scale. In point (a), *adjustments are recommended* in order to obtain state of the art radiation therapy. At (b), *immediate corrective actions need to be taken*, unless due to special circumstances, the clinical physicist decides that treatment can proceed. This delicate decision has to be discussed extensively in the centre and documented for every treatment method.

Test methods

Contrary to the NCS Report 8[17] no particular test methods will be proposed in this report. It is essential however that the test method should be able to distinguish parameter changes smaller than the action levels. The suggested action levels in this report are expressed in one quantity only. The responsible physicist can choose any suitable test method, provided that the action levels can be and will be correctly converted. For example, in Section 5.1 an action level of 2% is suggested for the quality index (QI). If an institution prefers to determine the 80 per cent depth (d_{80}) instead of the quality index in order to test the stability of the quality index of a 8 MV photon beam, the allowed ±2% variation has to be converted as follows, in accordance with the first order Taylor expansion:

$$\Delta d_{80} = \Delta QI \times \frac{\mathrm{d}}{\mathrm{d}QI} d_{80}(QI) + \mathcal{O}(\Delta QI^2)$$

Figure 2 shows the relation between the quality index, the 80 per cent depth and the nominal energy according to the BJR Supplement 17[2]. As can be seen from this Figure, the corresponding quality index and 80 per cent depth of an 8 MV photon beam are 0.72 and 7.6 cm respectively. In this domain $\frac{\mathrm{d}}{\mathrm{d}QI}d_{80}(QI)$ equals 27.5 cm. Consequently: $\Delta d_{80} = \pm 2\% \times 0.72 \times 27.5\mathrm{cm} = \pm 0.4\mathrm{cm}$. This conversion assumes that both the quality index and the 80 per cent depth are equally suited as a measure of the nominal energy. This is not the case for higher energies ($E_{nom} > 15$ MV), where the relation between the nominal energy and the quality index becomes more steep.

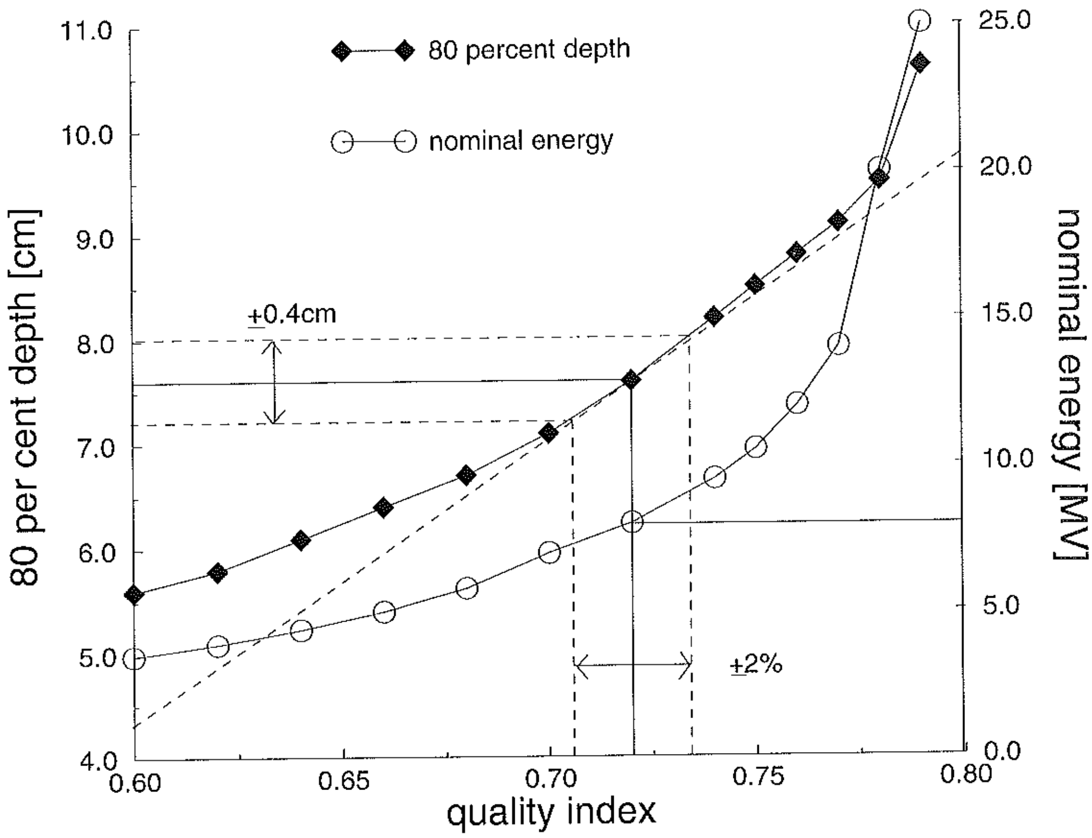


Figure 2: The relation between the quality index, the 80 per cent depth and the nominal energy

Remarks

The following remarks can be made concerning the results presented in the histograms and tables in this report:

- The meaning of the abbreviations is: D=daily, W=weekly, M=monthly, A=annually, (3M=once every three months, etc.).

- In a single case an institution may have more than just one procedure for checking a parameter. For instance: a parameter can be checked on a weekly and annual basis, while more stringent tolerance levels are applied in the annual procedures than in the weekly procedures. In the histograms showing the variations in test frequencies amongst institutions, always the highest test frequencies are indicated.

- If in an institution different tolerance levels are applied during different test procedures, always the most stringent tolerance level is represented in the histograms. Consequently, slight discrepancies may occur between the tolerance level histograms and the test frequency histograms.

- In the tables representing an intercomparison of recommended tolerance levels, the action levels are always given followed by any tolerance levels in brackets.

- Various checks may be implicit. For example, since door interlocks (and many other devices) are used daily, then it may be assumed that these are checked continuously. Obviously this is insufficient[9] and the histograms only represent the test frequencies of tests as part of a *formal* routine.

Radiotherapy in The Netherlands

In 1993 about 30,000 new patients[2] were treated with 61 electron accelerators in 21 radiotherapy institutions in The Netherlands. The distribution of these patients over the institutions is represented in Figure 3. It is clear that a lot of variation exists in the size of the institutions. Over 30% of the patients is treated in the four largest institutions.

To make a fair intercomparison between the time monthly spent on quality control of an electron accelerator, they are subdivided into three classes:

class I : accelerators with one photon beam and no electron beams
class II : accelerators with one photon beam and several electron beams
class III : accelerators with two (or more) photon beams and several electron beams

Figure 4 represents the (machine) time monthly spent on QC for the different classes of electron accelerators in The Netherlands. The average QC time monthly spent is 13.2 hours for class I accelerators, 18.1 hours for class II accelerators and 22.0 hours for class III accelerators. It should be noted, that most values are roughly estimated and sometimes it is very

[2]New patients are here defined as those patients that got a referral to a radiation therapy centre due to a tumour diagnosis and are irradiated for the first time at this tumour.

hard to distinguish time spent on preventive maintenance from time spent on quality control. Nevertheless, the differences in QC time are striking, especially for class III accelerators.

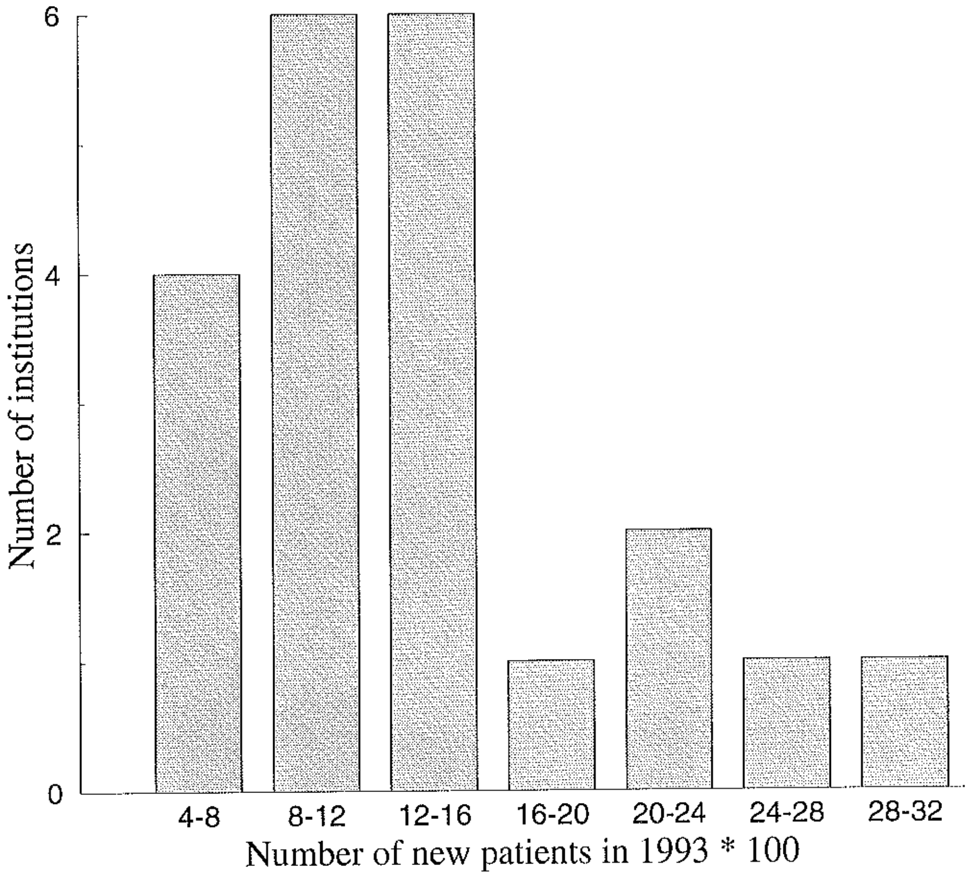


Figure 3: Distribution of new patients treated with electron accelerators in 1993 among 21 radiotherapy institutions in The Netherlands

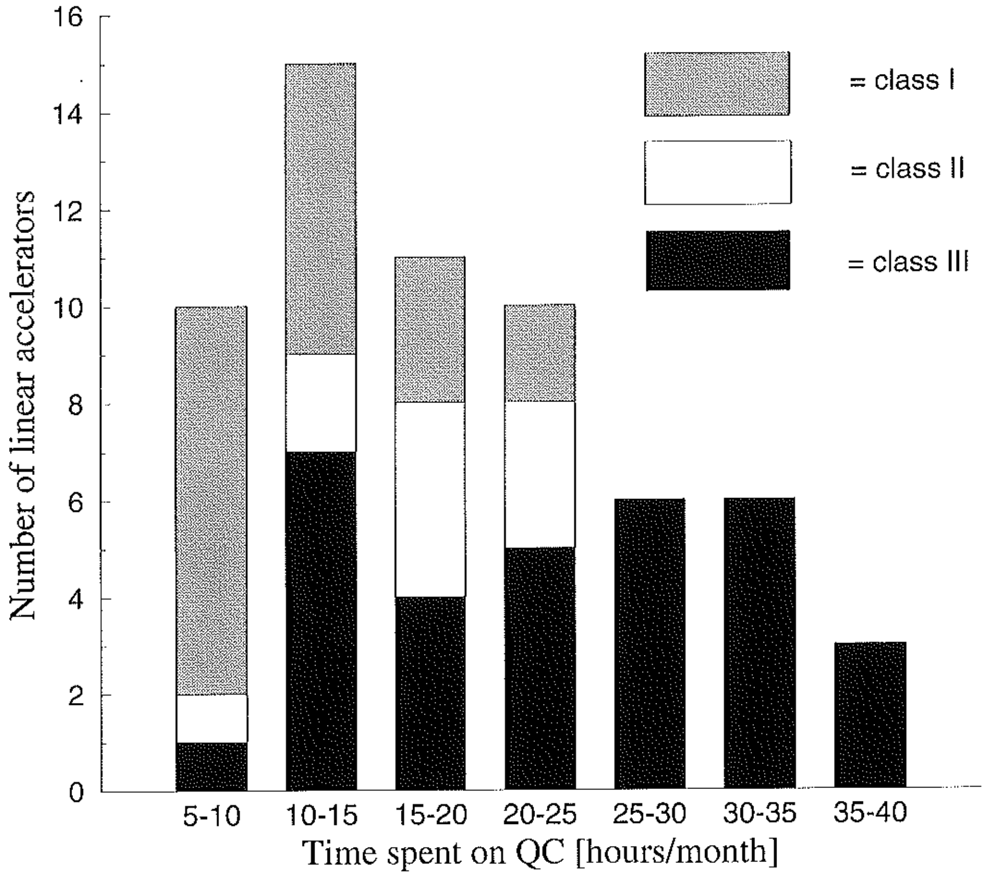


Figure 4: Distribution of the time monthly spent on quality control of class I, II and III accelerators in The Netherlands

1. Safety systems

1.1 *Safety systems directly accessible to the user*

inter-institutional survey

Executing QC procedures concerning safety systems directly accessible to the user generally does not take much time. Very often these procedures are just simple functional tests, so little variation is expected in method or time. The test frequency, however, varies a lot, as can be seen in Figures 5-10.

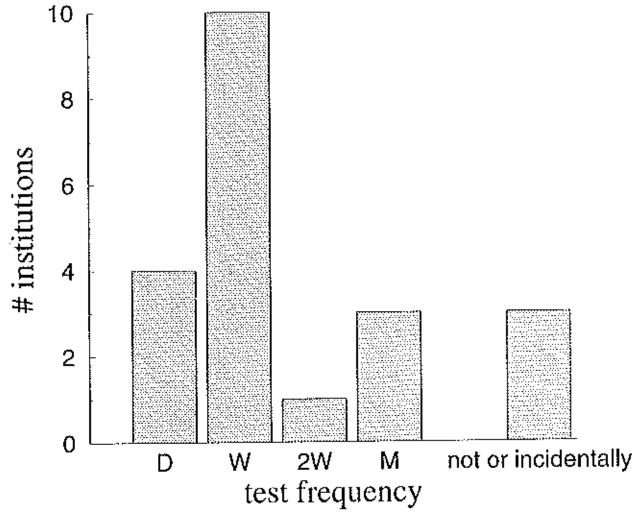


Figure 5: Frequency distribution of the check of warning lights and acoustic signals

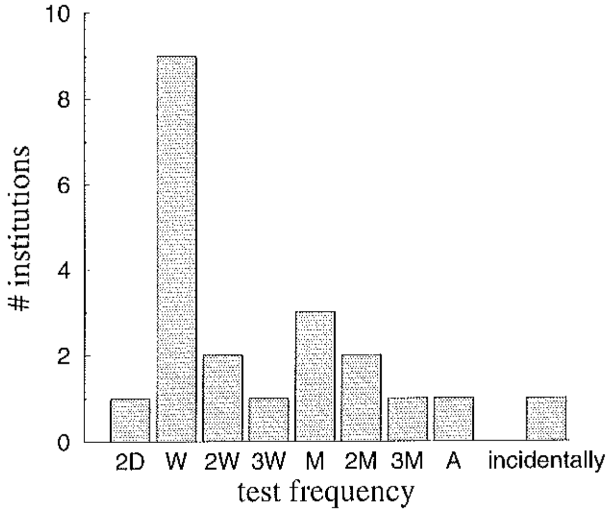


Figure 6: Frequency distribution of the check of the electrical interlock which should interrupt the irradiation if the treatment door is opened

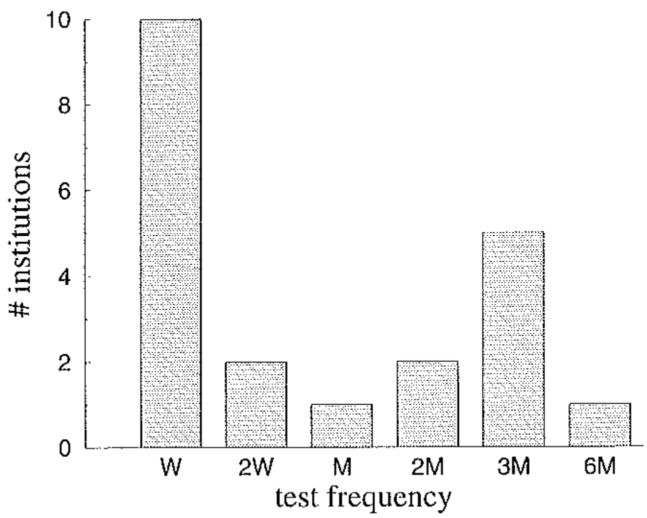


Figure 7: Frequency distribution of the check of the emergency stop push buttons

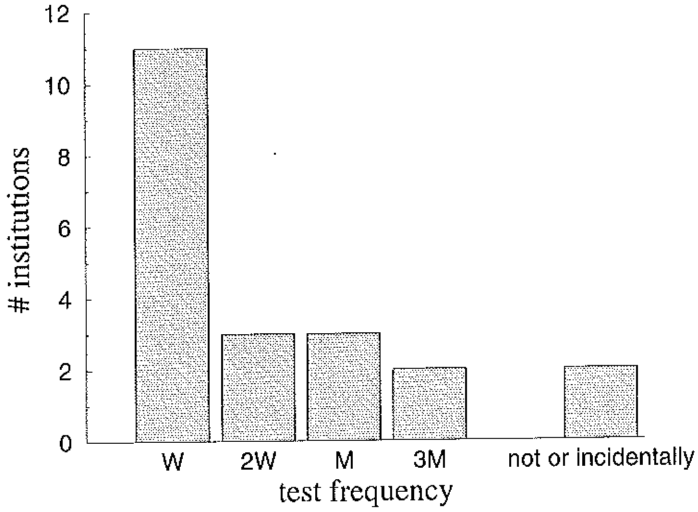


Figure 8: Frequency distribution of the check of the anti-collision systems

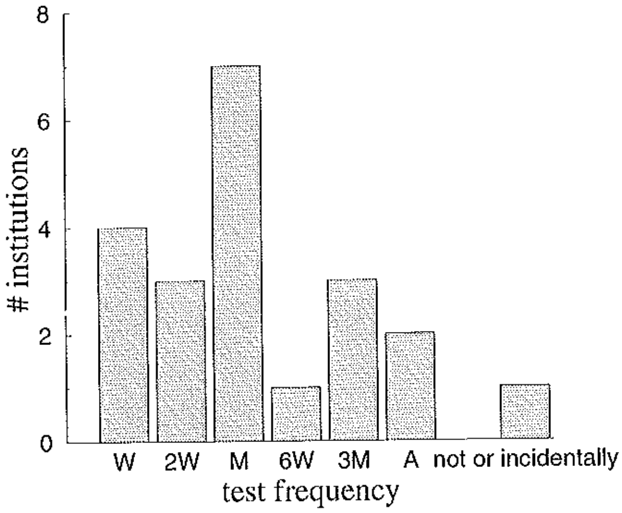


Figure 9: Frequency distribution of the check of the end-course cutoffs

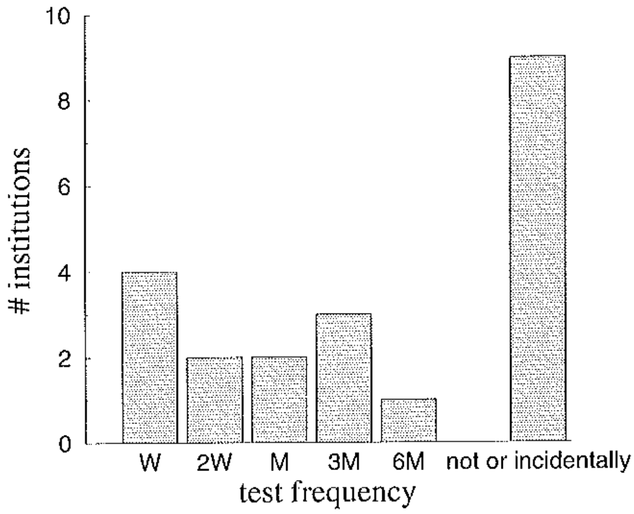


Figure 10: Frequency distribution of the check of the electrical interlock which prevents irradiation with photon beams when accessories for electron radiation are fitted and vice versa

intercomparison of recommendations

Table 2: Intercomparison of recommended test frequencies for several safety devices

report	*frequency*					
	warning lights	*entrance door*	*emergency stop*	*anti-collision*	*end-course*	*accessories*
AAPM	-	D	M	-	-	-
Brahme et al.	D	D	D	D	-	-
DIN	-	-	-	-	-	-
IEC	-	-	-	-	-	-
IPSM	M	M	M	M	M	-
Johansson et al.	D	D	-	D	-	-
NCS	-	M	A	W	A	3M
SFPH	D	D	D	D	M	D

minimum requirements

test	*frequency*	*warning lights*	:	3M
,,	,,	*entrance door*	:	3M
,,	,,	*emergency stop*	:	A
,,	,,	*anti-collision*	:	M
,,	,,	*end-course*	:	A
,,	,,	*accessories*	:	A

The suggested minimum test frequencies of the first four items are considerably lower than most recommended frequencies. The reason for the difference in test frequency of the warning lights and entrance door interlock is that it is very likely that a malfunction will be noticed very soon by the radiation technologists during their routine work.

1.2 *Safety devices not directly accessible to the user*

Every dose monitor system will for safety reasons be composed of two radiation detectors situated within the radiation head. Both monitor systems should be able to function independently. The readings of the two systems have to agree closely and each system has to be capable of terminating the irradiation. A third device, a timer, is installed to terminate the irradiation in case both monitor systems fail. To check the functioning of these safety devices, drastic actions are often required, like temporary adjusting calibration factors or altering cable connections.

inter-institutional survey

The test frequencies for the proper functioning of these devices is checked is plotted in Figures 11, 12 and 13.

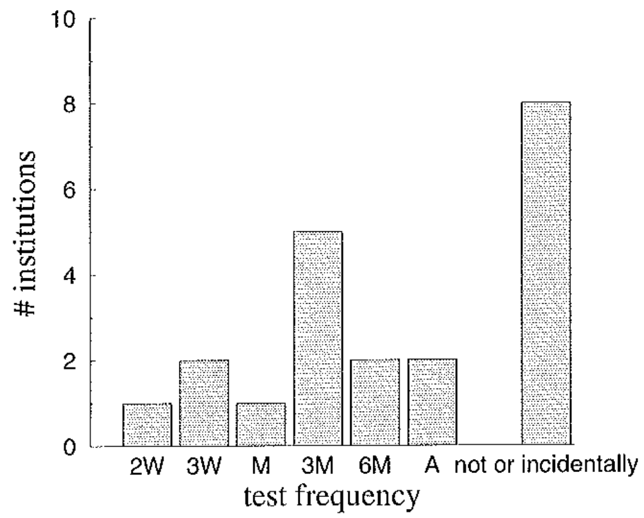


Figure 11: Frequency distribution of the check that if the readings of the two radiation detectors of the dose monitoring system differ more than a certain threshold value an irradiation interrupt will occur

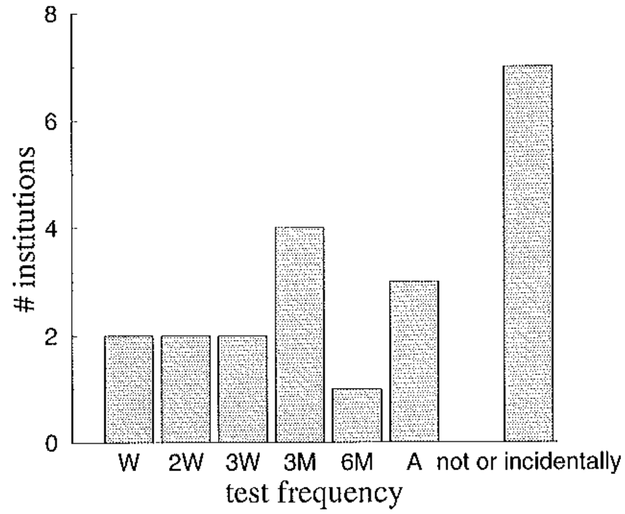


Figure 12: Frequency distribution of the check that each dose monitor system is capable of terminating the irradiation

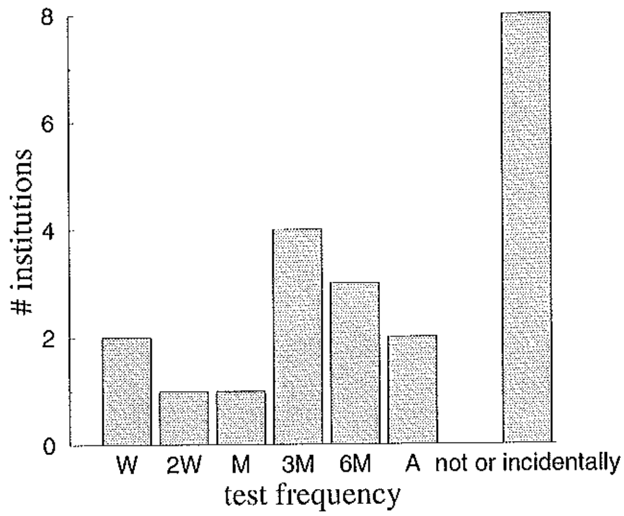


Figure 13: Frequency distribution of the check that the timer terminates the irradiation when the preselected time is finished

intercomparison of recommendations

Table 3: Intercomparison of recommended test frequencies for several safety devices not directly accessible to the user

report	*frequency*		
	irradiation stop at discrepancy of monitor readings	*both monitors capable of terminating irradiation*	*irradiation stop when preselected time is finished*
AAPM	-	-	-
Brahme et al.	-	-	-
DIN	-	-	-
IEC	-	-	-
IPSM	-	-	-
Johansson et al.	-	-	-
NCS	3M	3M	3M
SFPH	M	6M	6M

minimum requirements

These tests are not considered to be mandatory

In many electron accelerators it is not trivial to check the beam safety devices mentioned in this paragraph and artificial interventions in hardware are necessary. This means that these tests should be performed with extreme care. Consequently, performing these tests carries high risks and for that reason these tests are not considered to be mandatory. Because the functioning of the beam safety devices can be of extreme importance, radiation technologists should be trained in recognising possible malfunctioning.

2. Mechanical parameters

The verification of mechanical parameters generally has two purposes. On one hand it serves to guarantee an accurate irradiation treatment and on the other hand it gives an impression of long-term changes due to wear of mechanical points.

2.1 *Isocentre position*

The definition of the term isocentre accepted by the IEC is 'the centre of the smallest sphere through which the axes of the radiation beams pass in all conditions'. Although this point must be located on the basis of radiation measurements, the approximate position may be checked by mechanical methods.

2.1.1 Cross-hair position

inter-institutional survey

All but one institution verify the correspondence between the mechanical axis of the collimator and the light beam axis on a regular basis. Verification takes place by checking the displacement of the projection of the cross-hair while turning the collimator around its axis. The reference height of the projection of the cross-hair is normally taken at the isocentre, although three institutions (also) prefer to verify the displacement at a greater distance for example at the ground level.

Figure 14 displays the variations in test frequencies among all institutions, while Figure 15 shows the variations in permitted deviations for all institutions that check the movement of the projection of the cross-hair at the isocentre.

intercomparison of recommendations

Table 4: Intercomparison of recommended test frequency and tolerance level for the position of the cross-hair

report	*frequency*	*tolerance level*
AAPM	M	Ø 2mm
Brahme et al.	W(M)	Ø 2mm; (Ø 1mm)
DIN	3M	-
IEC	M	Ø 2mm
IPSM	D/W	Ø 2mm
Johansson et al.	W/M	Ø 2mm
NCS	M	Ø 2mm
SFPH	M	Ø 2mm

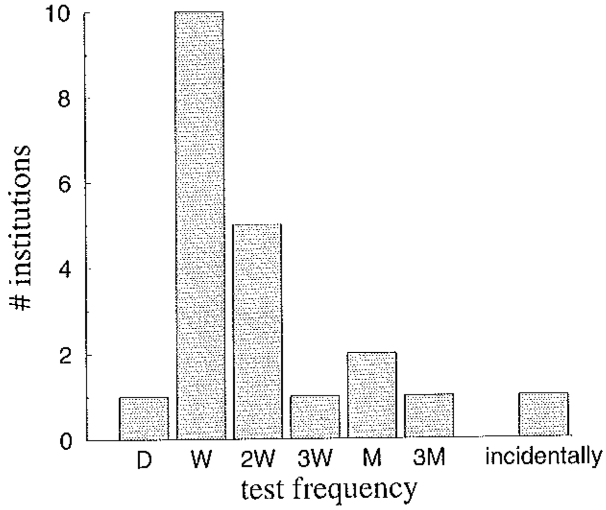


Figure 14: Frequency distribution of the checks of the correspondence between the mechanical axes of the collimator and the light beam axes

minimum requirements

test frequency	:	M
action level	:	Ø 2mm

The coincidence of the mechanical axis of the collimator and the light beam axis is also of great importance for the determination of the mechanical isocentre, laser beam alignments and verification of the isocentric table rotation. This emphasises the importance of this test and should therefore be performed with a minimum frequency of at least once per month.

2.1.2 Mechanical isocentre position

The mechanical isocentre is defined as the point of intersection of gantry rotation axis and the collimator rotation axis. Due to mechanical tolerances and bending of the radiation head this point cannot be determined unambiguously, but one can define a small sphere which envelops the isocentre.

inter-institutional survey

As shown in Figure 16, it turned out that almost all institutions verify the position of the mechanical isocentre at a regular basis, although the test frequencies vary considerably. Most institutions apply a 2 mm variation between the intersections of the different projections of the cross-hair as a tolerance level. The exact determination of location of the isocentre is also of

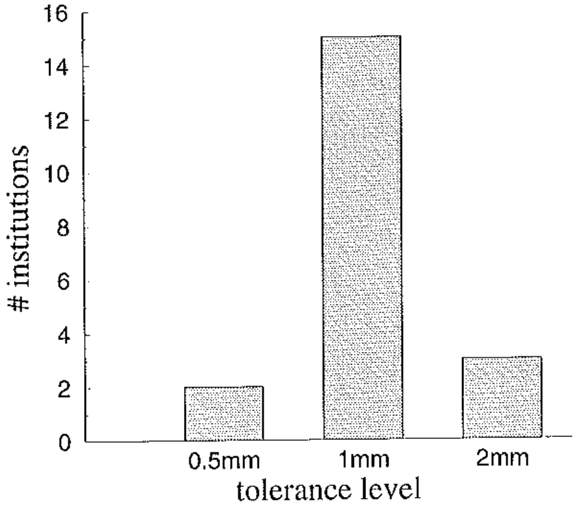


Figure 15: Distribution of tolerated diameter of the circle which envelops the movement of the cross-hair during rotation of the collimator

great importance for identifying deviations in the laser alignment system, the optical distance indicator and treatment table scales.

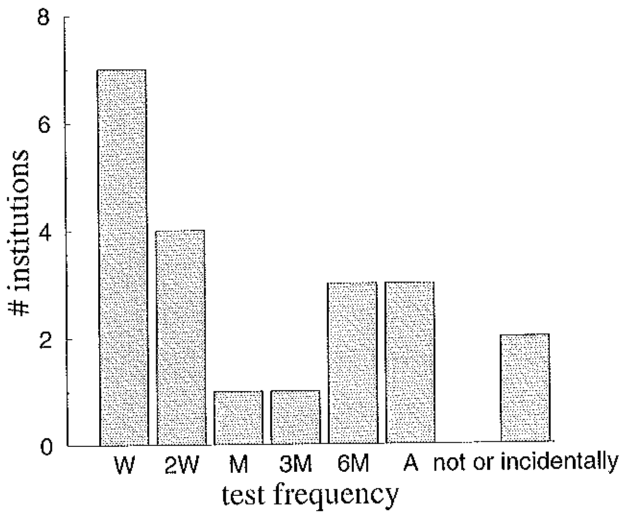


Figure 16: Position of the mechanical isocentre

intercomparison of recommendations

Table 5: Intercomparison of recommended test frequency and tolerance level for positioning of the mechanical isocentre

report	*frequency*	*tolerance level*
AAPM	A	Ø 2mm
Brahme et al.	M(A)	Ø 2mm; (Ø 1mm)
DIN	3M	-
IEC	M	Ø 2mm
IPSM	M	Ø 2mm
Johansson et al.	6M-2A	Ø 2mm
NCS	M	Ø 2mm
SFPH	M	Ø 2mm

minimum requirements

test frequency	:	A
action level	:	Ø 2mm

Changes in major mechanical tolerances are unlikely to take place on a weekly or monthly frame; therefore, a minimum test frequency of once a year is suggested.

2.1.3 Radiation isocentre position

inter-institutional survey

The radiation isocentre is defined as the point of intersection of the radiation beam axes at different gantry angles and collimator angles. The location of the radiation isocentre can be established by closing the collimators to the smallest possible field size and placing a film in the plane defined by the central axis of the beam when the gantry is rotated. The film will be exposed at different gantry angles resulting in a star-shaped picture. If correct, all radiation beams will coincide at the same point, the radiation isocentre. Only three institutions regularly verify the position of the radiation isocentre in this way.

intercomparison of recommendations

In none of the reports any suggestion is given with regard to periodic control of the radiation isocentre.

minimum requirements

test frequency	:	A
action level	:	Ø 2mm

(exclusively for accelerators with beam limiting systems which can generate small fields for which the central beam axis can be clearly discriminated)

The described method is a simple way for identifying the radiation isocentre, although it requires high technical performances from the beam limiting system in order to obtain field widths of a few millimetres. Therefore, a minimum test frequency of once a year is suggested for all electron accelerators with a beam limiting system which could generate small fields. A field width of 3 to 5 mm might be ideal, although in general it is essential that the central beam axis can easily be distinguished.

2.1.4 Laser alignment

inter-institutional survey

A complete laser alignment control can be distinguished into two checks. Firstly, it should be checked that the point of intersection of all lasers coincides with the isocentre. Figure 17 shows the frequencies of this check, which is carried out on a regular basis in all institutions. The tolerance level ranges from 0.5 mm to 2 mm at the isocentre.

Secondly, one could check whether the different beams describe horizontal and vertical planes. It turned out that five institutions periodically check the beam alignment. An often used method here is to compare the projection of the lasers with reference markers on the floor and walls.

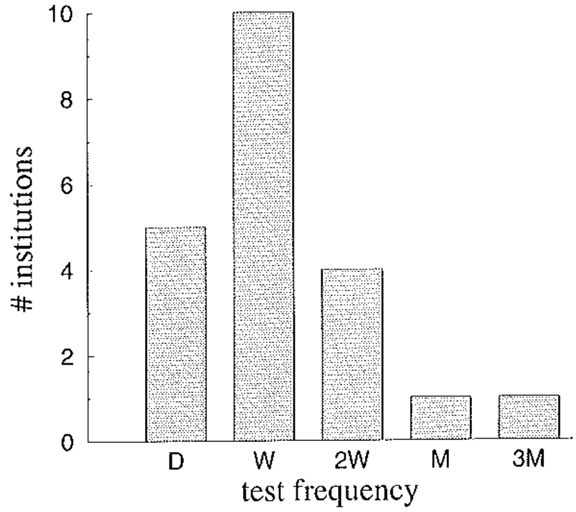


Figure 17: Frequency distribution of the positioning check of the lasers

intercomparison of recommendations

Table 6: Intercomparison of recommended test frequencies and tolerance levels for the laser alignment check

report	*frequency*	*tolerance level*
AAPM	D	±2mm
Brahme et al.	W	-
DIN	-	-
IEC	-	-
IPSM	M	±2mm
Johansson et al.	W	±3mm; (±2mm)
NCS	-	-
SFPH	-	-

minimum requirements

test frequency	:	M
action level	:	±2mm at the isocentre

Laser alignment is not included the IEC, DIN, SFPH nor the NCS report, because the laser system is often considered as an external system independent of the accelerator. Nevertheless, the laser alignment is of great importance and a minimum test frequency of the laser system of once per month is suggested.

One could check the laser alignment at the isocentre or one could mark the projection of the lasers on the walls during acceptance testing and check the projections with these markers as a QC procedure. Unfortunately this latter method does not foresee slight changes in the position of the isocentre. Therefore, the laser check at the isocentre is preferable if not both tests are performed, although the second method has the advantage that the laser beams are checked on horizontality and verticality.

2.2 *Optical distance indicator*

inter-institutional survey

All institutions do check the accuracy of the optical light indicator on a regular basis, as can be seen in Figure 18. The test frequencies range from daily to once every three months. The variation in the tolerance levels at the isocentre is given in Figure 19. About half the number of institutions also checked the accuracy of the optical distance indicator at distances other than the isocentre and handled less stringent tolerance levels in regions 10 cm or 20 cm distant from the isocentre.

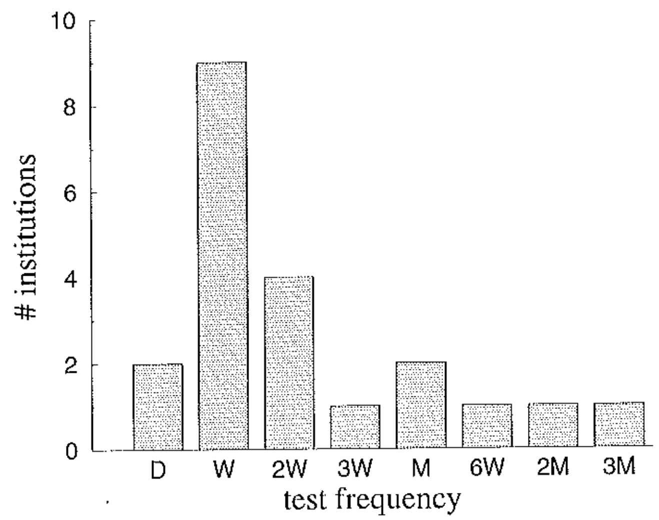


Figure 18: Frequency distribution of the checks of the accuracy of the optical distance indicator

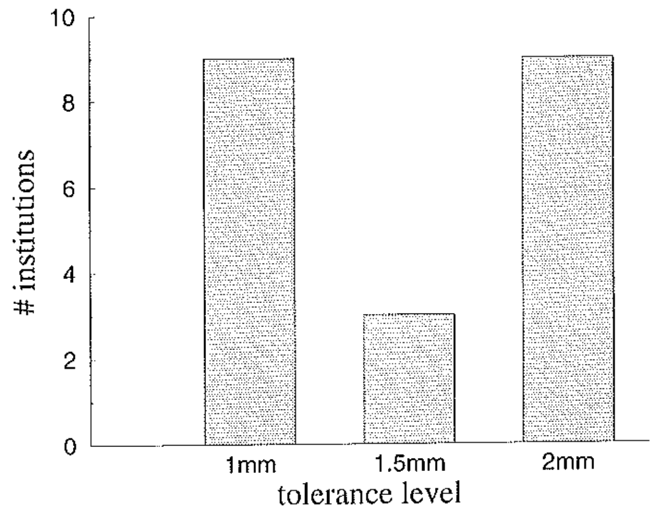


Figure 19: Tolerance level distribution of the check testing the accuracy of the optical distance indicator at the isocentre

intercomparison of recommendations

Table 7: Intercomparison of recommended test frequencies and tolerance levels for the optical distance indicator calibration

report	*frequency*	*tolerance level*
AAPM	M	±2mm
Brahme et al.	D	±2mm; (±1mm)
DIN	3M	-
IEC	6M	±5mm
IPSM	W	±2mm
Johansson et al.	D	±3mm
NCS	W	±1.5mm
SFPH	M	±3mm; (±2mm)

minimum requirements

test frequency	:	M
action level	:	±2mm (normal treatment distance ±20cm)

A lot of variation exists between the recommended test frequencies and tolerance levels in the various reports. The differences in tolerance values are due to the fact that the optical distance indicator is only linear in a specific range around the normal treatment distance. A tolerance level is suggested of ±2mm within the range of the normal treatment distance + or - 20 cm.

2.3 *Geometrical field size indication*

inter-institutional survey

This check is normally carried out by projecting various light fields at graph paper (with 1-mm graduations) at a horizontal plane at isocentric height and is not limited to testing the agreement between the indicated field size and the actual field size. Very often the light fields are also checked on symmetry, parallelism and rectangularity. The different test frequencies are shown in Figure 20. The tolerance levels range from 1 mm to 2 mm per collimator jaw.

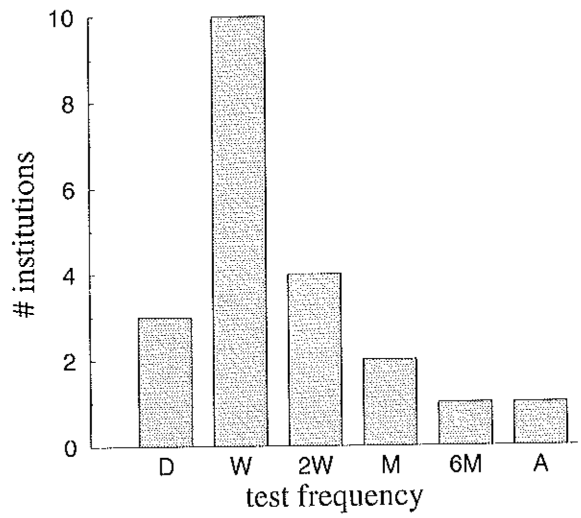


Figure 20: Frequency distribution of the checks of the accuracy of the position of the collimator jaws (size)

intercomparison of recommendations

Table 8: Intercomparison of recommended test frequencies and tolerance levels for the position of the collimator jaws

report	*frequency*	*tolerance level*
AAPM	M	±2mm
Brahme et al.	W/M	±2mm or ±1.5%, whichever is greater; (±1%)
DIN	3M	-
IEC	M	±2mm for field sizes ≤20cm×20cm ±3mm for field sizes >20cm×20cm
IPSM	W/M	±2mm
Johansson et al.	D	±3mm
NCS	2W	±1mm or ±1%, whichever is greater
SFPH	W	±2mm

minimum requirements

test frequency	:	M (A)
action level	:	±2mm

A minimum test frequency of once per month is suggested for checking the congruence between the indicated field and the actual light field for at least two different field sizes. More extended tests are suggested which include checks on symmetry, parallelism and rectangularity of the collimator jaws and sagging due to gravity at gantry angles of 90° and 270°. These tests should be performed at least once a year.

2.4 *Treatment table*

2.4.1 Isocentric rotation

inter-institutional survey

If the treatment table is mounted on a turntable, this turntable should rotate around an axis that passes through the isocentre. A commonly used method for checking the alignment of the rotation axis is the examination of the movement of the cross-hair projection on the treatment table during the isocentric rotation. Figure 21 shows the test frequencies of this check in the various institutions. The maximum displacements of the projections of the cross-hair tolerated at isocentric height is displayed in Figure 22. It should be noted that six institutions (also) checked the wander of the cross-hair projection at a lower level, for instance the ground level. The tolerance values for the check at the lower level range from 3 mm to 4 mm.

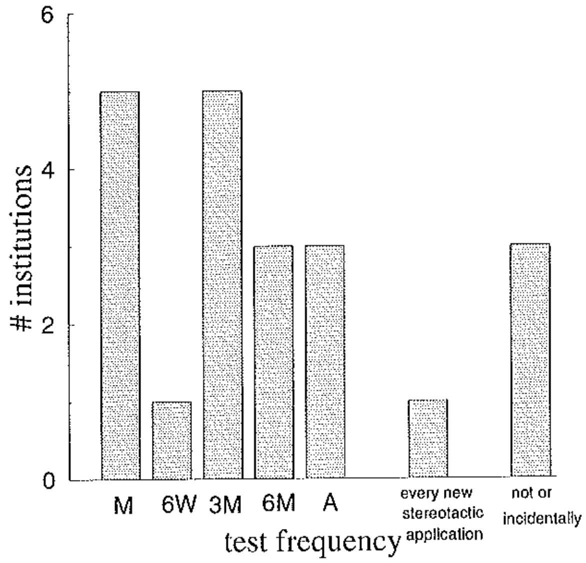


Figure 21: Frequency distribution of the checks of the isocentric rotation of the table around the plateau axes.

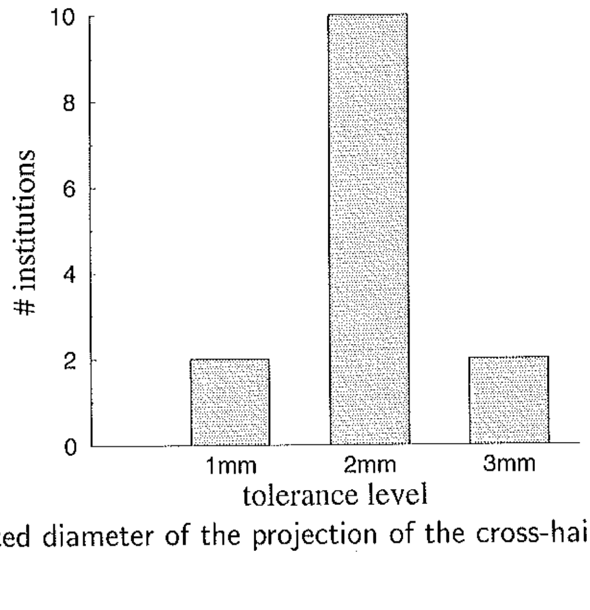


Figure 22: Tolerated diameter of the projection of the cross-hair at isocentric height

intercomparison of recommendations

Table 9: Intercomparison of recommended test frequencies and tolerance levels at isocentric height for the isocentric rotation control

report	*frequency*	*tolerance level*
AAPM	A	Ø 2mm
Brahme et al.	6M	-
DIN	-	-
IEC	M[1]	Ø 2mm
IPSM	-	-
Johansson et al.	6M-2A	Ø 3mm
NCS	A	Ø 2mm
SFPH	M	Ø 2mm

minimum requirements

test frequency	:	A
action level	:	Ø 2mm at isocentric height

A test frequency of at least once per year is suggested. If, however, certain treatment methods require accurate isocentric rotations, this test should be performed at higher frequencies and should also include a check of the accuracy of the mechanical and electrical scales.

2.4.2 Slope of the table top

inter-institutional survey

The treatment table top should be horizontal. Figure 23 shows the frequency distribution of the test that checks to what extent this condition is met. A tolerance level of 2.5 mm/m for a table without load and 5 mm/m for a loaded table is often applied. The slope of the table top is mostly checked by means of a spirit level, although one institution prefers to relate the slope of the table top to the laser system.

[1] if important for positioning the patient, otherwise occasional tests

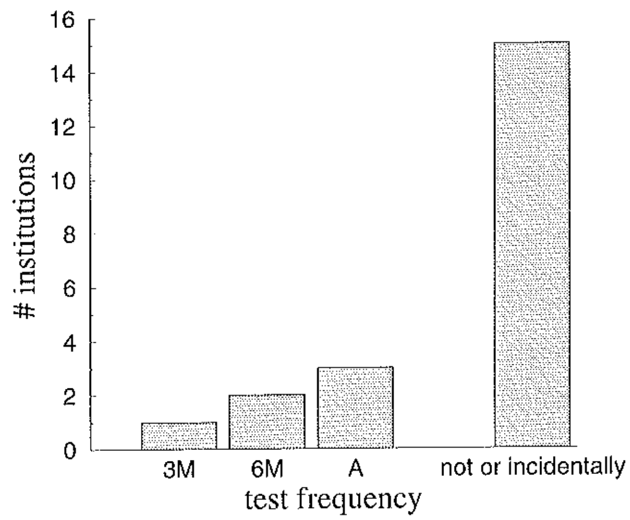


Figure 23: Frequency distribution of the checks of the slope of the table top

intercomparison of recommendations

Table 10: Intercomparison of recommended test frequencies and tolerance levels of the verification of the slope of the table top

report	*frequency*	*tolerance level*
AAPM	-	-
Brahme et al.	M	-
DIN	-	-
IEC	-	-
IPSM	-	-
Johansson et al.	-	-
NCS	A	5.0 mm/m in the longitudinal direction 2.5 mm/m in the lateral direction
SFPH	6M	5 mm (2mm) variation of the table height, while the table is longitudinally (laterally) moved through its full course with load placed

minimum requirements

test frequency	:	A
action level	:	5.0 mm/m in the longitudinal direction 2.5 mm/m in the lateral direction

An annual test is suggested concerning the slope of the treatment table. The test should be performed with a spirit level in both longitudinal and lateral directions at the isocentric table rotation angles of 0°, 90° and 270°. The tolerance levels are 5.0 mm/m and 2.5 mm/m for longitudinal and lateral directions, respectively.

2.4.3 Vertical movements of the treatment table

inter-institutional survey

To test the vertical movement of the treatment table, most institutions measure the displacement of the projection of the cross-hair, while moving the table top vertically. Figure 24 shows the different test frequencies of this check among the institutions. Most institutions apply a tolerance level of a 2 mm horizontal shift.

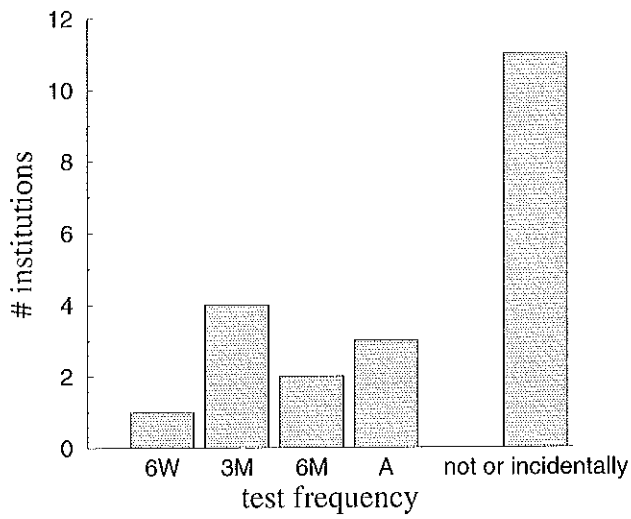


Figure 24: Frequency distribution of the test of the horizontal shift during vertical motion

intercomparison of recommendations

Table 11: Intercomparison of recommended test frequencies and tolerance levels of the test of the horizontal shift during vertical motion

report	*frequency*	*tolerance level*
AAPM	-	-
Brahme et al.	M	2mm (1mm)
DIN	-	-
IEC	M[2]	2mm
IPSM	-	-
Johansson et al.	6M-2A	-
NCS	A	2mm
SFPH	M	2mm

minimum requirements

test frequency	:	A
action level	:	2mm

It is suggested that the horizontal shift during vertical motion of the table top is checked at least once a year. If, however, special treatment methods require accurate vertical displacements, more frequent quality control should be performed. The check is most easily performed by determining the horizontal displacement of the projection of the cross-hair while lowering the table top 50 cm around the normal treatment distance. It is essential however that the collimator axes is as vertical as possible. This could be checked using a plumb line.

2.4.4 Rigidity of the treatment table

inter-institutional survey

The rigidity of the treatment table is mostly checked by placing a specified weight at the end of the table top and examining the bending. A lot of differences exist in the specified weights (ranging from 50 kg to 135 kg) and the resulting displacement of the table top end from the isocentre. Consequently comparison of the tolerance levels is not possible but range from an allowable table sag from 2 mm to 5 mm. The test frequencies can however be compared and are listed in Figure 25. Three institutions verified in addition to the longitudinal bending also the lateral bending due to a weight laterally placed on the table.

[2] if important for positioning the patient, otherwise occasional tests

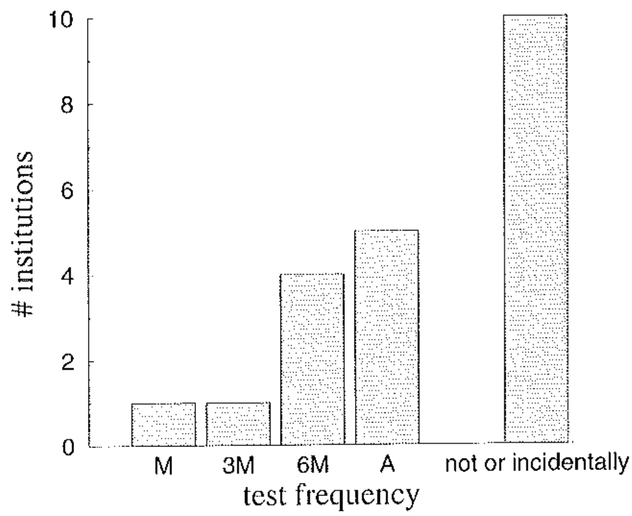


Figure 25: Frequency distribution of the checks of the table top rigidity

intercomparison of recommendations

Table 12: Intercomparison of recommended test frequencies for rigidity control of the treatment table

report	*frequency*
AAPM	A
Brahme et al.	-
DIN	A
IEC	A
IPSM	-
Johansson et al.	-
NCS	A
SFPH	6M

minimum requirements

test frequency	:	A
action level	:	5.0 mm in the longitudinal direction
		2.5 mm in the lateral direction

An annual test is suggested concerning the rigidity of the treatment table. A load of 50 kg is placed at the end of the table top while the table top is in its outermost longitudinal or lateral position. The tabel top sag may not exceed 5.0 mm or 2.5 mm in the longitudinal or lateral direction respectively. Special attention should be drawn to the sag of the Melinex, tolerances of mechanical bearings and twists of the treatment table, although no action levels are suggested here.

2.4.5 Scales on the treatment table

inter-institutional survey

In Figure 26 the test frequencies are represented from the checks of the electrical and mechanical readings.

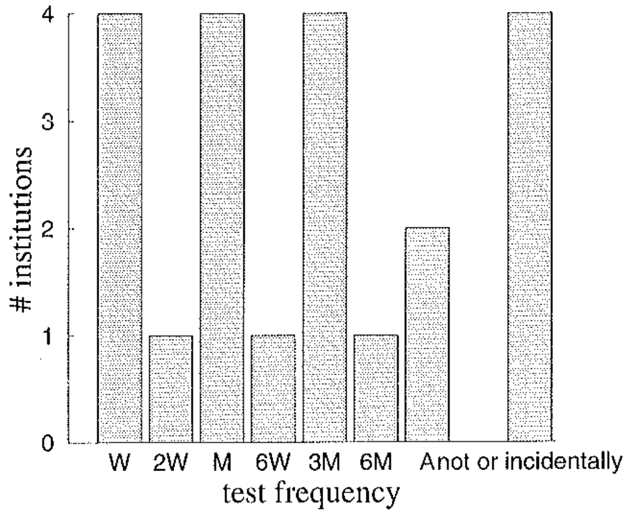


Figure 26: Frequency distribution of the checks of the correspondence between table position readings at the treatment control panel, the mechanical scale readings and the actual position

intercomparison of recommendations

Table 13: Intercomparison of recommended test frequencies and tolerance levels of the checks of the scales on the treatment table

report	*frequency*	*tolerance level*
AAPM	M	±2mm
Brahme et al.	M	-
DIN	-	-
IEC	-	-
IPSM	W/M	±2mm
Johansson et al.	6M-2A	-
NCS	A	±2mm
SFPH	6M	±2.5mm

minimum requirements

test frequency	:	A (M)
action level	:	±2mm

This test serves to check the linearity of the various scales on the treatment table more than to calibrate the absolute zero positions. It is suggested to check this linearity at least once a year and the errors should not exceed 2 mm. If the scales are used to position a patient relatively to a reference mark, then a minimum frequency of once per month is suggested.

2.5 *Gantry rotation*

inter-institutional survey

The accuracy of the mechanical and electrical readings of the gantry rotation angle is mostly checked with a spirit level hold against a true surface at the radiation head verifying the readings at gantry angles of 0°, 90°, 180° and 270°. Figure 27 shows the test frequencies of this check. The tolerance levels principally range from 0.5° to 1°, although two institutions apply a tolerance level of 0.2° and 0.25°.

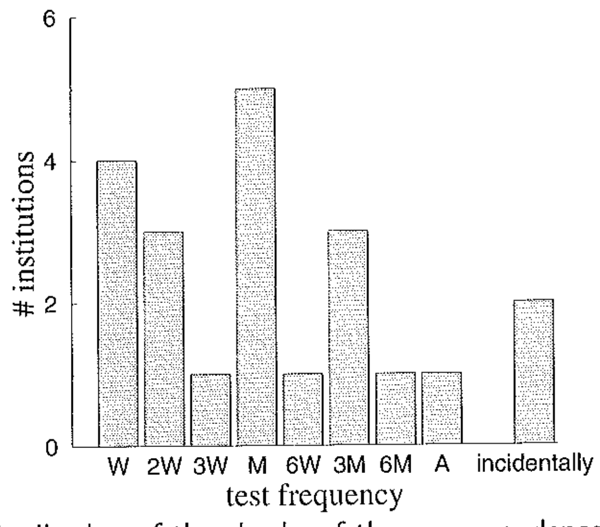


Figure 27: Frequency distribution of the checks of the correspondence between gantry angle selected at the treatment control panel and the actual position

intercomparison of recommendations

Table 14: Intercomparison of recommended test frequencies and tolerance levels of the checks of the gantry angle readings

report	*frequency*	*tolerance level*
AAPM	M	$\pm1°$
Brahme et al.	W/M	$\pm1°(\pm0.5°)$
DIN	6M	-
IEC	A	$\pm0.5°$
IPSM	W/M	$\pm0.5°$
Johansson et al.	6M-2A	-
NCS	3M	$\pm0.5°$
SFPH	M	$\pm0.5°$

minimum requirements

test frequency	:	6M
action level	:	$\pm1°$

Both mechanical and electrical readings of the gantry angle could be checked in the four major directions with the aid of a spirit level, but also the projection of the cross-hair at the walls could be of great help. It is suggested that both electrical and mechanical readings are tested in the four main directions at least twice a year.

2.6 *Collimator rotation*

The mechanical and electrical readings of the collimator rotation angle should be consistent with the actual collimator rotation angle. With the gantry at 90° or 270° and a collimator angle in one of the major directions, the collimator jaws should be either horizontally or vertically. Both mechanical and electrical readings can be checked by placing a small spirit level on the jaws. Assuming that both readings do not deviate in the same way, it suffices to check the mechanical and electrical reading on conformity.

inter-institutional survey

Figure 28 shows the frequencies of the checks of the electrical readings.

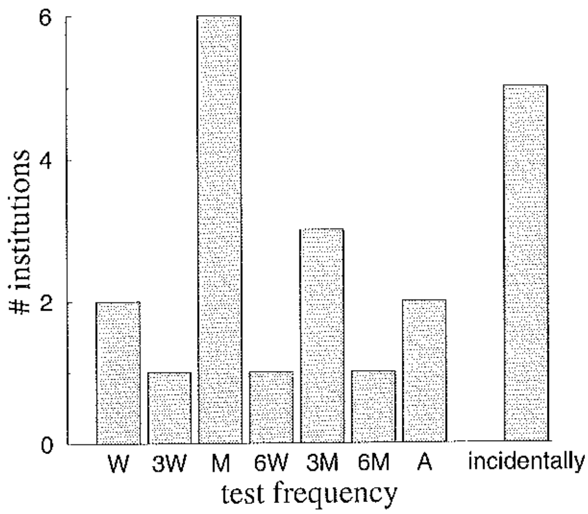


Figure 28: Frequency distribution of the checks of the correspondence between collimator angle selected at the treatment control panel and the actual position

intercomparison of recommendations

Table 15: Intercomparison of recommended test frequencies and tolerance levels of the checks of the collimator angle readings

report	*frequency*	*tolerance level*
AAPM	M	$\pm 1°$
Brahme et al.	W/M	$\pm 1°$; ($\pm 0.5°$)
DIN	6M	-
IEC	A	$\pm 0.5°$
IPSM	W/M	$\pm 0.5°$
Johansson et al.	6M-2A	-
NCS	3M	$\pm 0.5°$
SFPH	M	$\pm 0.5°$

minimum requirements

test frequency	:	6M
action level	:	$\pm 1°$

A minimum frequency of twice a year is suggested for the test of the mechanical and electrical collimator readings. The projection of the cross-hair could be to the laser beams or reference marks on the floor or walls.

3. Correspondence between light field and radiation field

inter-institutional survey

The primary goal of this test is to check the size and the location of the light field in relation to the size and location of the radiation field. All institutions verify the correspondence between both fields by comparing a film measurement of the radiation field with marks indicating the boundaries of the light field. The tolerance levels range from 1 mm to 2 mm per jaw for small field sizes up to 1% of the field length or width for larger field sizes. One institution applies a less stringent tolerance value of 3 mm per jaw.

Except for one institution, the radiation field-light field correspondence is periodically checked for all applied radiation qualities. Some centres apply besides the film method other methods:

- one institution uses a phosphorescent screen
- four institutions use a water phantom with scanning mechanism
- one institution uses an air scanner

In the latter two cases the digital readings are directly compared with the size and location of the radiation field. The correspondence of the light field size and the radiation field size is normally checked only at a gantry angle of 0°, but one institution also checks this correspondence at a gantry angle of 90°, 180° and 270°. Figure 29 represents the different test frequencies of the radiation field-light field correspondence check. Various numbers of field sizes are periodically checked in the different institutions as shown in Figure 30.

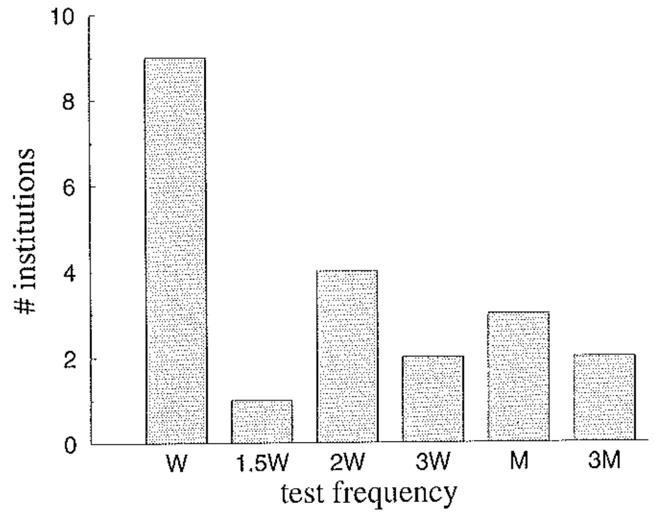


Figure 29: Frequency distribution of the checks of the correspondence between light field and the radiation field

intercomparison of recommendations

Table 16: Intercomparison of recommended test frequencies and tolerance levels of the checks of the correspondence between light field and radiation field

report	*frequency*	*tolerance level*
AAPM	M	±2mm or ±1%, whichever is greater
Brahme et al.	W	±2mm or ±1.5% whichever is greater; (±1mm)
DIN	3M	-
IEC	M	±3mm for field sizes ≤20cm×20cm ±5mm for field sizes >20cm×20cm
IPSM	M	±2mm
Johansson et al.	W/M	±3mm; (±2mm)
NCS	2W	±2mm or ±1%, whichever is greater
SFPH	M	±2mm

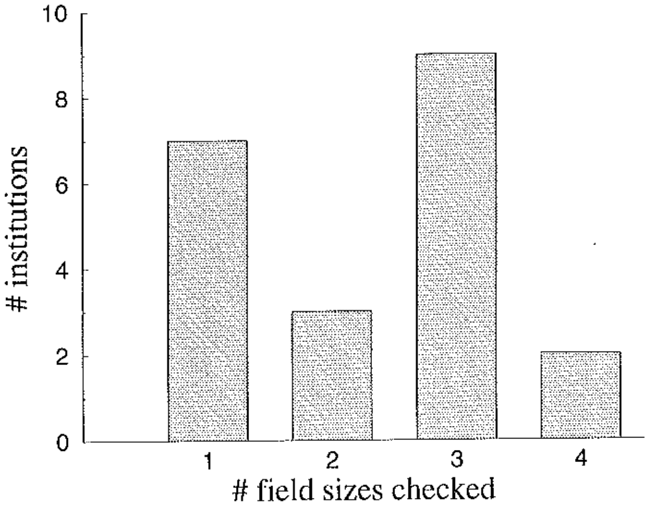


Figure 30: Number of different field sizes periodically checked

minimum requirements

test frequency	:	M minimal one field size 3M minimal three field sizes
action level	:	$\pm$ 2 mm or $\pm$1%, whichever is greater

It is suggested that the size and location of the photon fields and light fields is tested at least once per month for one field size. This test should be extended to three different field sizes (5cm $\times$ 5cm, 10cm $\times$ 10cm and 30cm $\times$ 30cm or the maximum field size) at least once every three months.

4. Flatness and symmetry of radiation fields

The methods employed in The Netherlands for periodically verifying the flatness and symmetry of therapy beams turned out to vary as can be seen in Figure 31. Many institutions use more than one method with different test frequencies to check the beam flatness and symmetry. The most often employed method though is scanning the dose rate in two orthogonal directions in a water phantom at a given reference depth. The seven institutions who periodically check the beam flatness and symmetry at gantry angles of 90°, 180° and/or 270° make use of an air scanner or an array of ionization chambers.

4.1 *Field flatness and symmetry of photon beams*

inter-institutional survey

The flatness and symmetry of a photon therapy beam is mostly checked for the maximum field size. Three institutions however also check the beam flatness and symmetry at at least two smaller field sizes. Six institutions check the beam flatness and symmetry along the diagonals of the radiation field besides the check along the major axis.

Most institutions do not accept an asymmetry greater than 2%. The beam flatness is not a well defined quality in the technical literature. Generally a flattened area is defined perpendicular to the beam axis in which the dose rate distribution should be reasonably flat. Two different examples of a definition of a flattened area are given here in Figure 32. The tolerated maximum deviation from the mean dose rate varies between 1% and 3%. Figure 33 shows the different test frequencies of the beam flatness and symmetry check.

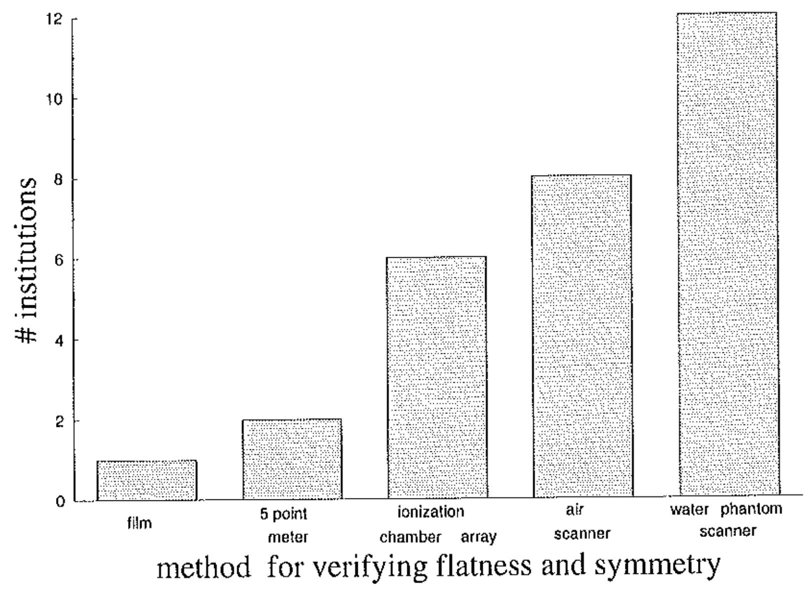
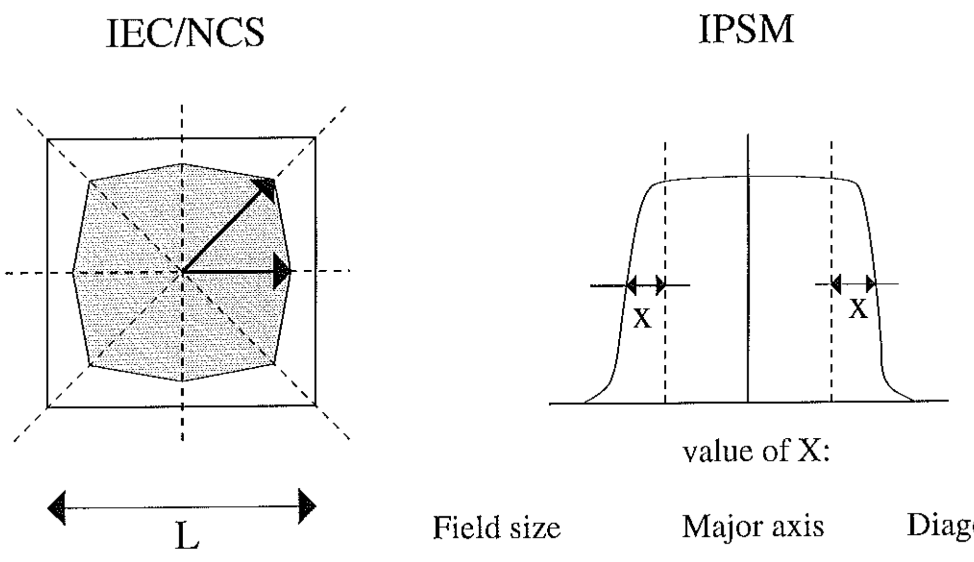


Figure 31: Distribution of different methods to check the flatness and symmetry of radiation beams



Major axis: 0.8*L/2

Diagonal: 0.7*L $\sqrt{2}/2$

Field size	Major axis	Diagonal
50-100mm	10mm	25mm
101-300mm	0.1*Field size	0.2*Field size + 5mm
301mm -Max	30mm	65mm

Figure 32: Definition of flattened area for photon beams as defined by the IEC and NCS and the IPSM

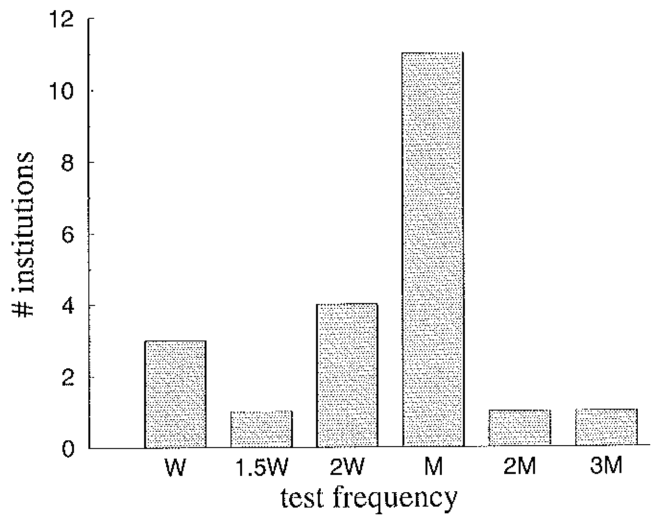


Figure 33: Frequency distribution of the field flatness check for photon beams

intercomparison of recommendations

Table 17: Intercomparison of recommended test frequencies and tolerance levels for the photon field flatness and symmetry

report	*frequency*	*tolerance level*	
		flatness	*symmetry*
AAPM	M	±2%	±3%
Brahme et al.	M	±4%; (±2.5%)	
	W		±3%; (±1.5%)
DIN	A[1]	-	-
IEC	W[2]	±3% (≤30cm×30cm) ±5% (>30cm×30cm)	±3%
IPSM	W	±1.5%	±3%
Johansson et al.	W/M	±3%; (±2%)	-
NCS	A	±3%	
	M		±3%
SFPH	M	±3%	±3%

minimum requirements

flatness

test frequency : A

action level : ±3% compared with a reference profile, except for the penumbra region

symmetry

test frequency : M

action level : ±3% within the flattened area

It is suggested that the flatness of the photon beams is extensively checked at least once a year, for example with a scanning water phantom. More simplified checks concerning symmetry are recommended with frequencies of once per month.

[1] 8 measurements of the 5-point test (4 gantry angles times 2 nominal energies) and 4 measurements of the scan test (2 radiation fields times 2 nominal energies)

[2] one energy each week with alternating four gantry angles with four collimator angles (i.e. four measurements each week)

4.2 *Field flatness electron beams*

inter-institutional survey

The uniformity of electron beams is mostly tested for the flattened area defined by the 90% isodose at a reference depth (see Figure 34). All institutions use the same methodology for examining the flatness of electron beams as they do for photon beams, although the field sizes for this check are smaller than for photon beams and range from 20 cm × 20 cm to 30 cm × 30 cm. Analogous to the situation of photon beams, the tolerance level for beam flatness varies between 1% and 3%. It should be noted that the only institution which also examines the flatness and symmetry of the electron beam by means of film scanning, applies a symmetry tolerance level of 7% in this case. During the annual examining of the electron beam flatness with an air scanner, a tolerance level of 1% is applied.

As can be seen in Figures 33 and 35 the flatness of the electron beams is generally less often examined than the flatness of the photon beams. Figure 36 displays the number of different field sizes for which the electron beam flatness is individually checked.

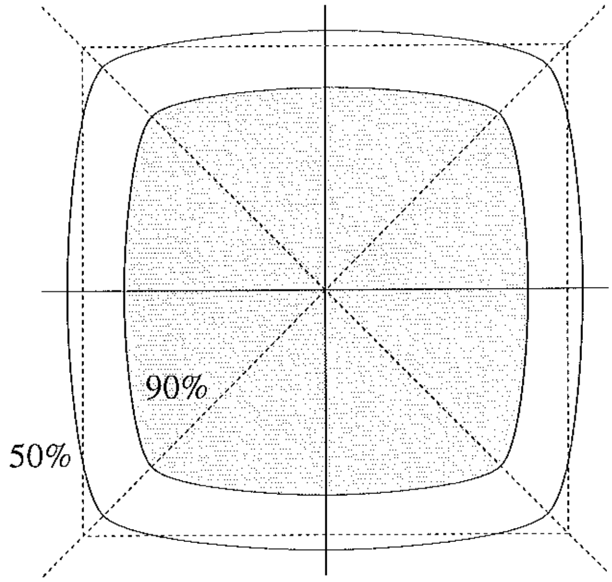


Figure 34: Commonly used definition of the flattened area of electron fields

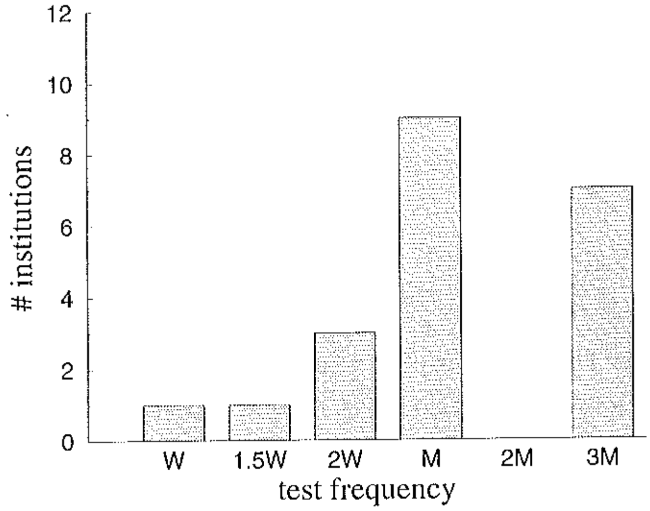


Figure 35: Frequency distribution of the field flatness check of electron beams

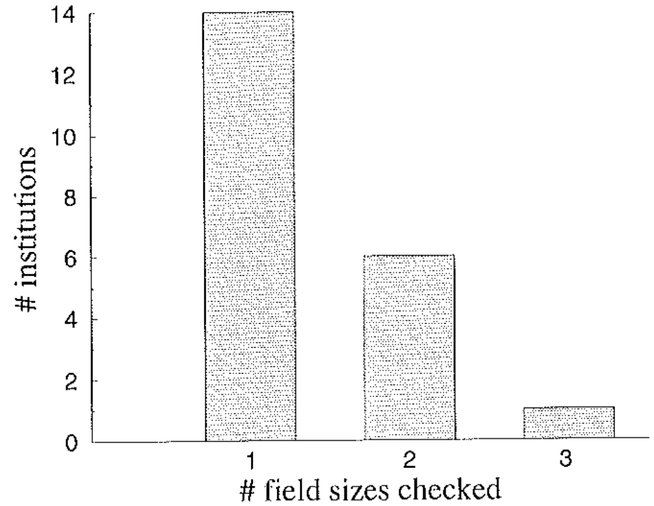


Figure 36: Distribution of the number of field sizes periodically checked on flatness

intercomparison of recommendations

Table 18: Intercomparison of recommended test frequencies and tolerance levels for the electron field flatness and symmetry control

report	*frequency*	*tolerance level*	
		flatness	*symmetry*
AAPM	M	±3%	±3%
Brahme et al.	M	±4%; (±2.5%)	
	W		±3%; (±1.5%)
DIN	A	-	-
IEC	M[3]	-	±5%
IPSM	W	1.03 for $\frac{\text{dose max. anywhere}}{\text{dose central axis}}$	±1.5%
Johansson et al.	W/M	±3%; (±2%)	-
NCS	M	1.03 for $\frac{\text{dose max. anywhere}}{\text{dose central axis}}$	±3%
SFPH	M	1.03 for $\frac{\text{dose max. anywhere}}{\text{dose central axis}}$	±3%

minimum requirements

flatness

test frequency : A

action level : ±3% compared with a reference profile, except for the penumbra region

symmetry

test frequency : M

action level : ±3% within the flattened area

It is suggested that the field uniformity of electron beams is extensively checked at least once per year for all applied energies, for example with a scanning water phantom. More simplified checks concerning symmetry are recommended with frequencies of once per month.

[3]for a scanning beam accelerator the IEC recommends a weekly test frequency

5. Beam energy

The quality of photon beams is generally characterised by the nominal accelerating potential expressed in megavolts (MV), while the quality of the near mono-energetic electron beams is characterised by its mean energy expressed in megaelectronvolts (MeV). However, from a clinical point of view we are more interested in the penetrating characteristics of a radiation beam than in its accelerating potential or mean energy.

5.1 *Beam quality of photon beams*

inter-institutional survey

Two different methods are accepted for checking the beam quality. About half the number of institutions check the beam quality by measuring a depth dose distribution along the beam axis using a water phantom provided with a scanning mechanism. Two institutions compare these percentage depth dose (PDD)-curves with a reference curve by eye. In these cases no clear-cut tolerance levels are defined. Almost every other institution examines the shape of the PDD-curve by verifying the quality index (I_{20}/I_{10}). However, the quality index is defined as the ratio of two measurements at fixed focus-detector distance (100 cm)[12, 15] which is related in a complicated way with phantom scans, where the focus-surface distance is constant[13]. Since we are only interested in constancy of the beam energies, this will have have no further implications.

Another often used method for checking the beam quality for consistency purposes is by making measurements at two depths at a reference SSD and field size. For megavoltage X-rays below about 20 MV, the ratio of measurements made at 5 cm and 15 cm depth is often considered as a sufficiently sensitive measure of beam quality. Figure 37 shows the test frequency of beam quality check, while the different tolerance levels are stated in Figure 38.

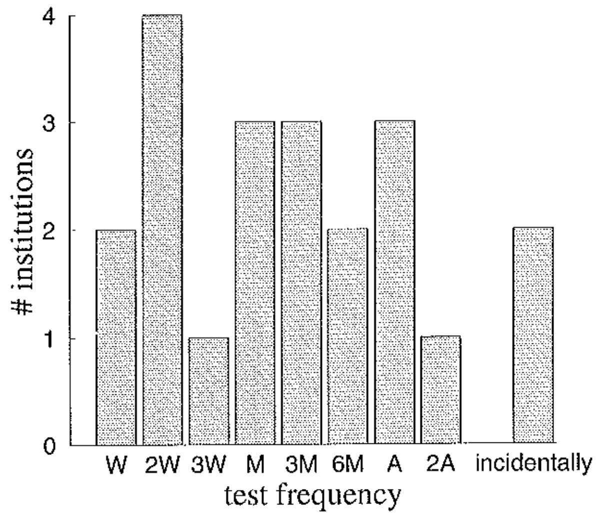


Figure 37: Frequency distribution of the beam quality check of photon beams

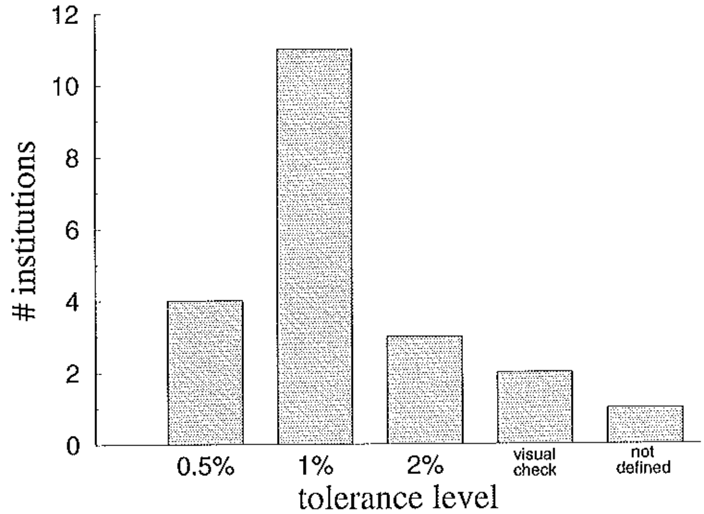


Figure 38: Distribution of the different beam quality tolerance levels applied

intercomparison of recommendations

Table 19: Intercomparison of recommended test frequencies and tolerance levels for beam quality check of photon beams

report	*frequency*	*tolerance level*
AAPM	M	±2% in I_{20}/I_{10}
Brahme et al.	M	±3mm; (±2mm) in d_{50}
DIN	6M	-
IEC	6M	±3mm in d_{80}
IPSM	M	±2mm in d_{80} for $E < 10$MV
		±3mm in d_{80} for $E > 10$MV
Johansson et al.	M	±2%; (±1.5%) in I_5/I_{15}
NCS	A	±0.005 in I_{20}/I_{10} for $E < 18$MV)
		±1% in PDD(10cm) for $E > 18$MV
SFPH	M	±1% in I_{20}/I_{10}

minimum requirements

test frequency	:	A
action level	:	±2% for the quality index

5.2 *Mean energy of electron beams*

inter-institutional survey

Contrary to the solution for photon beams, the verification of electron beam qualities does not always form a part of the QC-program as can be seen in Figure 39. Three different methods are used to verify the quality of electron beams. Similarly to photon beams most institutions examine the quality of electron beams by measuring a depth dose distribution using a water phantom. The 80%-depth (d_{80}) and the 50%-depth (d_{50}) can easily be extracted from the PDD-curve. As done for photon beams, the quality of electron beams is verified in five institutions by comparing the ratio of two dose rates measured at two different depths in a PMMA phantom to a reference value. Three institutions make use of a PMMA electron wedge filter in combination with a linear detector array or air scanner to examine the electron beam quality (Figure 40).

Because of the variety in methods used, the tolerance levels are sometimes expressed in megaelectronvolts, millimetres or percentages. Typical tolerance values are: 0.4 MeV or 0.5 MeV, 1 mm or 2 mm and 1% up to and including 3%. Two institutions do not apply quantitative tolerance criteria. Normally the beam energy of electron beams is checked under fixed conditions, i.e. a gantry angle of 0° and a specific field size only. One institution, however, also periodically examines the quality of the electron beam at gantry angles of 90°, 180° and 270° for various field sizes.

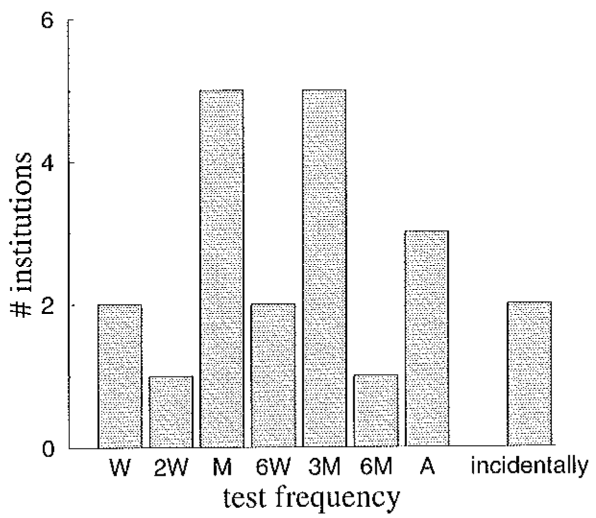


Figure 39: Frequency distribution of the check of the mean energy of electron beams

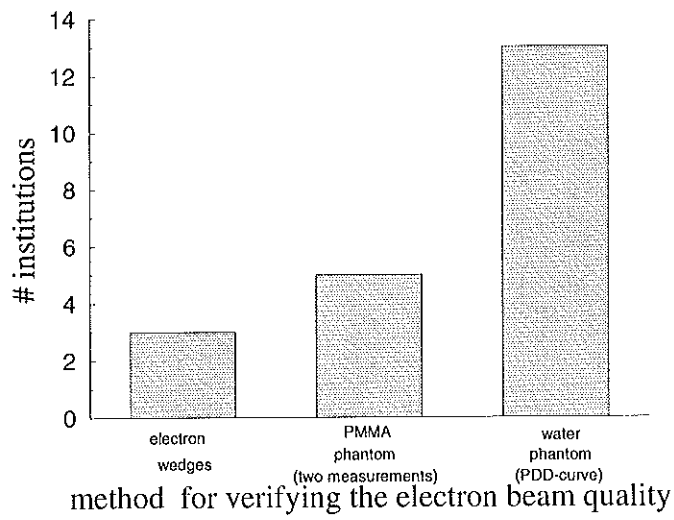


Figure 40: Distribution of the various methods used for checking the mean energy of electron beams

intercomparison of recommendations

Table 20: Intercomparison of recommended test frequencies and tolerance levels for mean energy checks of electron beams

report	*frequency*	*tolerance level*
AAPM	M	±2mm in therapeutic depth
Brahme et al.	M	±3mm; (±2mm) in therapeutic and practical range
DIN	6M	-
IEC	W[1]	±2mm in d_{80}
IPSM	M	$\pm(0.60\text{MeV}/E_{\text{nominal}}) \times 100\%$ in d_{80}
Johansson et al.	M	±8%; (±6%) in d_{50}
NCS	3M	±2mm in d_{50}
SFPH	M	±4% in d_{50}

minimum requirements

test frequency	:	6M
action level	:	±2mm for d_{50}

[1]one energy each week

6. Absolute dosimetry of radiation beams

Absolute dose determination is an essential part of QC-programmes. All Dutch radiotherapy institutions use NCS Reports 2 and 5[15, 16] as their protocol for the dosimetry of photon and electron beams, respectively.

6.1 *Photon beam dosimetry*

inter-institutional survey

The photon beam output is normally checked at a gantry angle of 0° or 90° and a field size of 10 cm × 10 cm, although one institution only verifies the dose calibration for a field size of 20 cm × 20 cm. For the determination of the absorbed dose at a reference point, the ionization chamber is mostly placed on the beam axis with the centre of the chamber at a depth of 5 cm for photon beams with a quality index up to 0.75 (E_{nom} < 10.5 MV[2]) and at a depth of 10 cm for photon beams with a quality index larger than 0.75. However, two institutions measure at the depth of the dose maximum. As can be seen in Figure 41 four institutions check the photon output daily. In three of these institutions this is done by the radiation technologists. The tolerance levels of the daily check procedures range from 2% to 3%. Figure 42 shows the different tolerance levels.

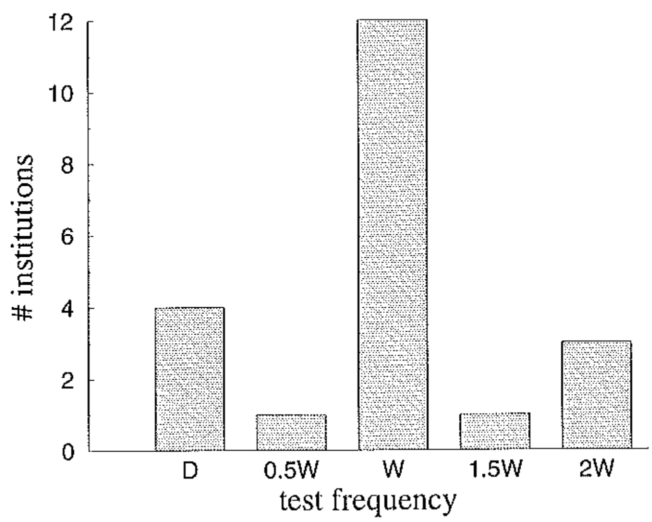


Figure 41: Frequency distribution of the checks of the photon output

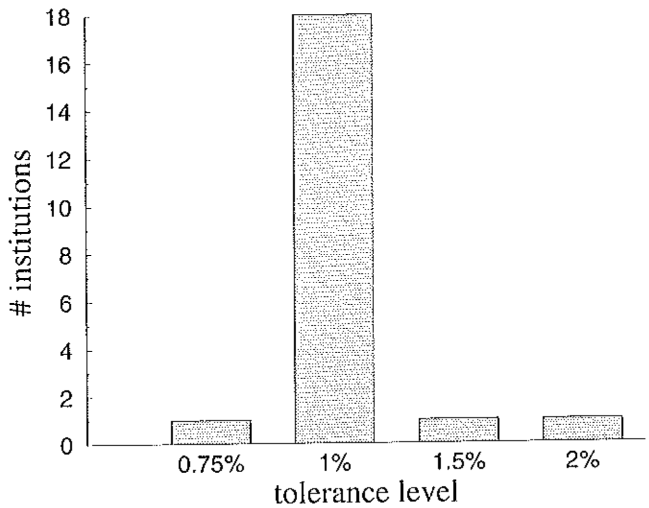


Figure 42: Distribution of the various photon output tolerance levels

intercomparison of recommendations

Table 21: Intercomparison of recommended test frequencies and tolerance levels for the photon output

report	*frequency*	*tolerance level*
AAPM	D	±3%
	M	±2%
Brahme et al.	D	±2%; (±1%)
DIN	W	-
IEC	W	-
IPSM	D	±2%
Johansson et al.	D	±3%; (±2%)
NCS	W	±2%
SFPH	D	±2%

minimum requirements

test frequency	:	2W
action level	:	±2%

inter-institutional survey

Almost all institutions check the electron beam output for a field size of 10 cm × 10 cm. Three institutions also examine the dose calibration at other field sizes. Only one institution does not periodically verify the electron output at a 10 cm × 10 cm field size, but applies a field size of 20 cm × 20 cm. Two institutions check several electron outputs at more than one gantry angle. Figure 43 shows the frequency distribution of electron output checks and the different tolerance values are shown in Figure 44.

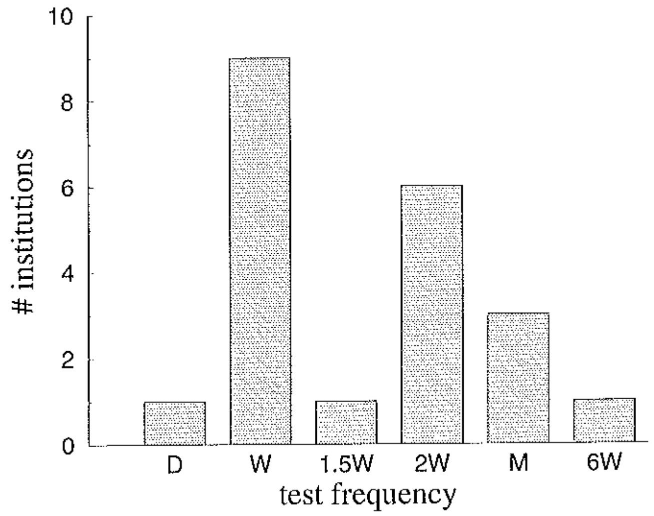


Figure 43: Frequency distribution of the checks of the electron output

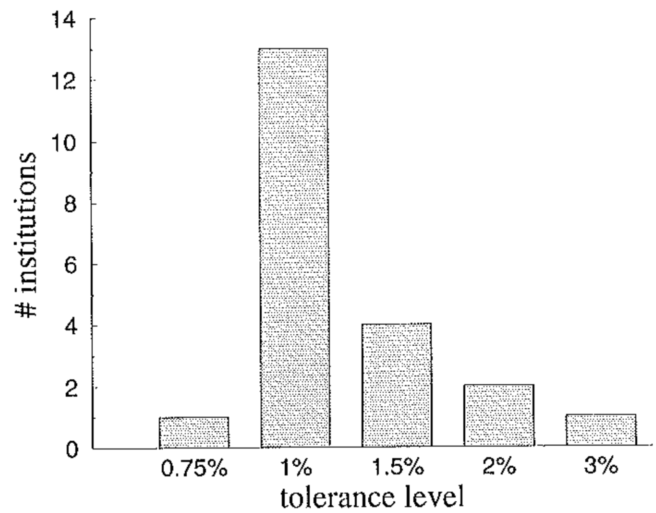


Figure 44: Distribution of the various electron output tolerance levels

intercomparison of recommendations

Table 22: Intercomparison of recommended test frequencies and tolerance levels for the electron output

report	*frequency*	*tolerance level*
AAPM	D	±3%
	M	±2%
Brahme et al.	D	±2%; (±1%)
DIN	W	-
IEC	W	-
IPSM	D	±2%
Johansson et al.	D	±3%; (±2%)
NCS	W	±2%
SFPH	D	±2%

minimum requirements

test frequency	:	2W
action level	:	±2%

7. Wedge filters

The wedge factor is defined as the ratio of the absorbed dose measured on the radiation beam axis at a reference depth with and without the wedge filter for the same number of monitor units. Internal wedge filters are positioned in the radiation head and held in position by a locking mechanism. The functioning of the locking system can be checked by periodically verifying the value of wedge factors.

inter-institutional survey

In Figure 45 the different frequencies are shown with which wedge factors are examined. Thirteen institutions measure the wedge factor at a gantry angle of 0°, while three institutions prefer a gantry angle of 90°. The tolerance levels principally vary between 1% and 2%, but one institution accepts deviations of the wedge factors with respect to a reference value up to 5%. In a number of institutions the wedge factor is determined at several collimator angles, as shown in Figure 46.

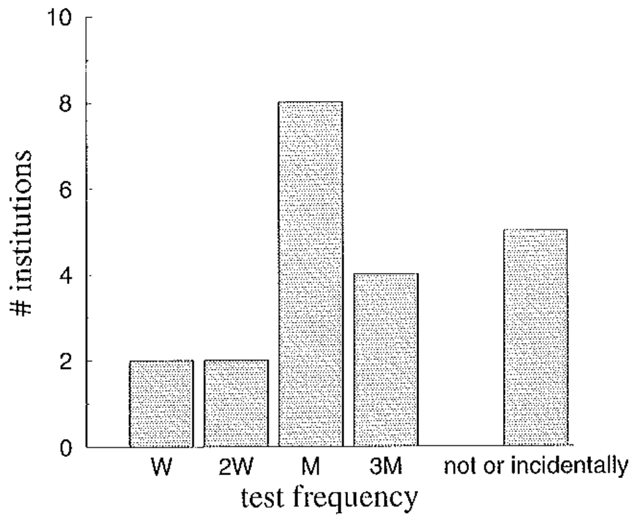


Figure 45: Frequency distribution of the checks of the wedge factors are checked

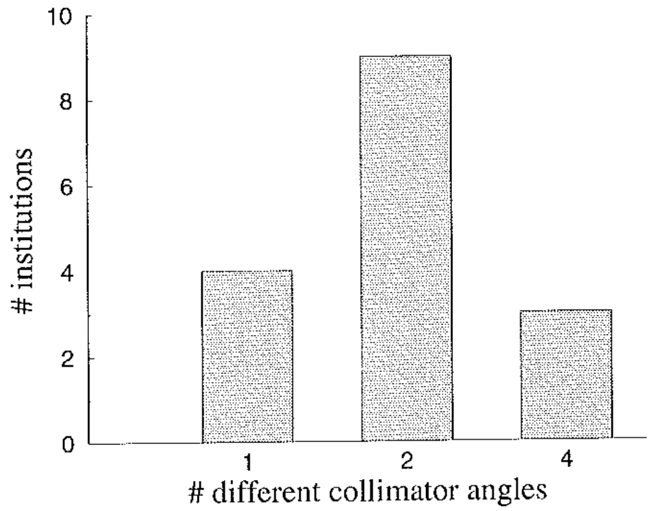


Figure 46: Distribution of the number of collimator angles applied for checking the wedge factor

intercomparison of recommendations

Table 23: Intercomparison of recommended test frequencies and tolerance levels of the wedge factor

report	*frequency*	*tolerance level*
AAPM	M	±2%
Brahme et al.	W	(visual check)
DIN	-	-
IEC	-	-
IPSM	M	-
Johansson et al.	6M-2A	-
NCS	M	±1%
SFPH	-	-

minimum requirements

test frequency : 3M
action level : ±2%

(gantry angle at 90° and two collimator angles)

8. Dose monitoring system

The relation between the reading of the dose monitor system and the dose delivery has to be proportional under all circumstances.

8.1 *Reproducibility*

inter-institutional survey

Most institutions check the reproducibility of the dose monitor system while examining the output by repeating these measurements once or twice. Six institutions, however, perform a separate control of the reproducibility of the dose monitoring system once a year or every two years. At least five measurements with 100 MU or 200 MU are made for one nominal energy. The tolerance levels range from 0.5% to 1%.

intercomparison of recommendations

Table 24: Intercomparison of recommended test frequencies and tolerance levels for the reproducibility checks of the dose monitor system

report	*frequency*	*tolerance level*
AAPM	-	-
Brahme et al.	6M	±0.5%; (±0.2%)
DIN	-	-
IEC	6M	±0.5%
IPSM	-	-
Johansson et al.	-	-
NCS	A	0.5% for $\frac{100\%}{\overline{R}}\sqrt{\sum_{i=1}^{n}\frac{(\overline{R}-R_i)^2}{n-1}}$
SFPH	6M	0.5% for $\frac{100\%}{\overline{R}}\sqrt{\sum_{i=1}^{n}\frac{(\overline{R}-R_i)^2}{n-1}}$

minimum requirements

> This test is not considered to be mandatory

8.2 *Linearity*

The relation between the number of monitor units U given and the reading of a dosimeter D should meet the following condition:

$$C = \frac{D}{U}$$

where C is a proportionality factor.

inter-institutional survey

Seven institutions verify the linearity of the dose monitor system once or twice a year by determining C for doses varying from 0.1 Gy up to and including 10 Gy. Variations in C up to 1% are accepted for doses greater than 1 Gy. For doses varying between 0.1 Gy and 1 Gy less stringent tolerance levels for variations in C are often allowed (1/dose[Gy]%).

intercomparison of recommendations

Table 25: Intercomparison of recommended test frequencies and tolerance levels for the linearity checks of the dose monitor system

report	*frequency*	*tolerance level*
AAPM	A	$\pm 1\%$
Brahme et al.	6M	$\pm 1.5\%$; ($\pm 0.5\%$)
DIN	6M	-
IEC	6M	$\pm 2\%$
IPSM	-	-
Johansson et al.	6M-2A	-
NCS	A	$\pm 1\%$ for $D \geq 1$Gy
		0.01Gy for $D < 1$Gy
SFPH	6M	$\pm 1\%$

minimum requirements

This test is not considered to be mandatory

8.3 *Dose rate effect*

Because of recombination effects, the reading of the dose monitor system will be dependent on the dose rate. If more than one dose rate is applied with an electron accelerator, the dose monitor has to be calibrated for each dose rate.

inter-institutional survey

Five institutions reported not to use more than one dose rate per electron accelerator. Four of the remaining sixteen institutions verify the lack of dependence of the dose rate of the dose monitor system every year or once every two years.

intercomparison of recommendations

Table 26: Intercomparison of recommended frequencies and tolerance levels for testing the influence of dose rate on monitor readings

report	*frequency*	*tolerance level*
AAPM	-	-
Brahme et al.	-	-
DIN	-	-
IEC	-	-
IPSM	-	-
Johansson et al.	6M-2A	-
NCS	A	±2%
SFPH	-	-

minimum requirements

This test is not considered to be mandatory

8.4 *Stability*

inter-institutional survey

Four institutions check the stability of the dose monitor system during the day. Measurements are performed at the beginning and at the end of a normal working-day. Discrepancies of 2% at most are allowed. Three of these institutions also check the stability after administering a (very) high dose, for example after an irradiation of 100 Gy or 15 minutes of irradiation at the highest dose rate. Variations of 2% are allowed.

intercomparison of recommendations

Table 27: Intercomparison of recommended test frequencies and tolerance levels for the stability check of the dose monitor system during a working-day

report	*frequency*	*tolerance level*
AAPM	-	-
Brahme et al.	M	±1.5%; (±0.5%)
DIN	A(M)	-
IEC	M/6M	±2%
IPSM	-	-
Johansson et al.	-	-
NCS	A	±2%
SFPH	-	-

minimum requirements

This test is not considered to be mandatory

8.5 *Gantry angle dependence*

inter-institutional survey

Five institutions regularly test the gantry angle dependence of the output for comparison with the results from the normal (weekly) photon output checks for all beam qualities. The output measured at the gantry angle of 0° (or 90°) is usually compared with the output measured at gantry angles in the remaining three cardinal directions. This is done by three institutions on an annual basis, while two institutions check the gantry angle dependence once every three months. Two of these institutions also check the output of all electron beams at different gantry angles.

intercomparison of recommendations

Table 28: Intercomparison of recommended test frequencies and tolerance levels for the gantry angle dependence of the output

report	*frequency*	*tolerance level*
AAPM	A	2% between smallest and largest output
Brahme et al.	M	2% (1%) between smallest and largest output
DIN	A	-
IEC	6M	3% between smallest and largest output
IPSM	3W/M	3% between smallest and largest output
Johansson et al.	3M-2A	-
NCS	A	3% between smallest and largest output
SFPH	M	3% between smallest and largest output

minimum requirements

test frequency	:	A
action level	:	3% between smallest and largest output

9. Arc therapy

inter-institutional survey

During arc therapy irradiation it is of great importance that both dose rate and gantry rotation velocity are accurately tuned, so the prescribed dose is equally spread between the starting angle and the stopping angle. Because of the large variety of intern processing systems among the various types of electron accelerators, no unequivocal control procedure can be applied. A large number of electron accelerators, however, stops irradiation when the prescribed dose has been delivered. Therefore, most QC procedures examine the coincidence of the actual stopping angle with the prescribed stopping angle. Differences up to 3° are allowed, although two institutions apply a tolerance level of 1° and even 0.5°. Figure 47 shows the test frequencies of the arc therapy check.

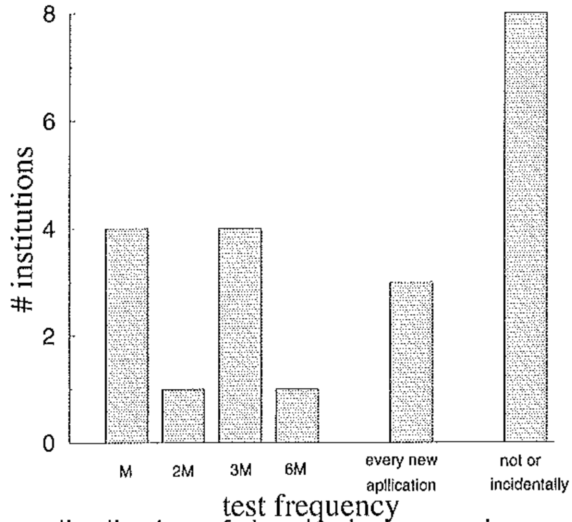


Figure 47: Frequency distribution of the checks concerning arc therapy accuracy

intercomparison of recommendations

Table 29: Intercomparison of recommended test frequencies and tolerance levels for the arc therapy control

report	*frequency*	*tolerance level*
AAPM	A	Mfrs. spec.
Brahme et al.	6M	-
DIN	M	-
IEC	M	5% or 3°
IPSM	M	-
Johansson et al.	-	-
NCS	M	5% or 3°
SFPH	M	-

minimum requirements

test frequency	:	3M
action level	:	5% or 3°

10. Leakage radiation

inter-institutional survey

Seven out of twenty one institutions perform tests regarding leakage radiation. Some of these institutions annually check the dose rate at the isocentre while the collimator jaws are closed. Other institutions (also) check the dose rate due to leakage at specific locations described in the acceptance test procedures.

Furthermore, in all institutions personal dosimeters were worn by all personnel who work frequently in the vicinity of radiotherapy accelerators. This list includes, but is not limited to, radiotherapists, physicists, accelerator maintenance personnel, technicians and radiation technologists. In none of the institutions an additional dosimeter is placed in the vicinity of the console to monitor the exposure.

intercomparison of recommendations

In none of the reports any suggestion is made with regard to periodic control of radiation leakage.

minimum requirements

test frequency :	A

Due to repair activities some lead blocks could be shifted a little, resulting in modification in radiation leakage. Therefore, it is recommended to check the radiation head on leakages at least once a year in conformity with the manufacturers acceptance test procedure.

Discussion and conclusion

Generally, the results of the questionnaire show a large variation in test frequencies, test methods, overall time spent on QC of electron accelerators and a somewhat smaller variation in tolerance levels. This diversity is mainly due to differences in philosophy with regard to QC and the differences in resources and machine time available. No correlation could be found between the test frequency and tolerance level of a certain parameter and the type or make of the accelerator since the number of institutions was too small compared to the number and distribution of the accelerators.

It should be noted, that the evaluation of the results of the questionnaire of some parameters should be regarded with special care. For example, the beam quality of photon beams is checked with frequencies varying between once every week up to once a year or even less often, with a median frequency of once every three months. When examining the different measurement procedures, the constancy of the beam quality during a weekly check will be performed with a simple PMMA phantom, while the institutions which verify the beam quality on a yearly basis often measure a complete PDD-curve. Consequently, different test frequencies might be related to different test methods. A similar situation may occur for symmetry checks. The availability of specific equipment may dictate the respective test frequencies. If an institution has the availability of a linear detector array or a quick check device, e.g. with five dosimeters, it is likely that, because of the small amount of effort to realize the set up, the frequency of the symmetry check will increase.

The implementation of the various minimum requirements in this report would result in all but one institution in adjustments in relation to their currently applied protocol. The average number of adjustments is 8.3 with a maximum of 17. Most of these alterations imply an additional check in parameter with an annual frequency or an increase of a test frequency and will therefore not require much increase of the total amount of time spent on QC.

Intercomparison of current practice in The Netherlands, minimum requirements and recommendations given in NCS Report 8

description	*para-graph*	*current practice*[1]		*minimum requirements*[2]		*NCS Report 8*	
		$f_{50\%}$	$f_{85\%}$	*minimum frequency*	*action level*	*recom-mended frequency*	*tolerance level*[3]
Safety systems							
warning lights	1.1	W	M	3M	-	-	-
entrance door	1.1	W	2M	3M	-	M	-
emergency stop	1.1	2W	3M	A	-	A	-
anti-collision	1.1	W	3M	M	-	W	-
end-course	1.1	M	A	A	-	A	-
accessories	1.1	3M	X	A	-	3M	-
dose monitor safety devices	1.2	6M	X	-	-	3M	-
Mechanical para-meters							
cross-hair	2.1.1	W	M	M	Ø2mm	M	Ø2mm
mechanical isocentre	2.1.2	2W	A	A	Ø2mm	M	Ø2mm
radiation isocentre	2.1.3	X	X	A	Ø2mm	-	-
lasers	2.1.4	W	2W	M	±2mm	-	-
ODI	2.2	W	M	M	±2mm	W	±1.5mm
field size indication	2.3	W	M	M	±2mm	W	±1mm or ±1%
isocentric rotation	2.4.1	3M	A	A	Ø2mm	A	Ø2mm
slope table top	2.4.2	X	X	A	5mm/m	A	5mm/m
vertical movement	2.4.3	X	X	A	2mm	A	2mm
rigidity table	2.4.4	A	X	A	5mm (2mm)	A	5mm (2mm)
scales table	2.4.5	3M	X	A	±2mm	A	±2mm
scales gantry	2.5	M	A	6M	±1°	3M	±0.5°
scales collimator	2.6	3M	X	6M	±1°	3M	±0.5°

[1] $f_{50\%}$ denotes the current median test frequency, while $f_{85\%}$ is the frequency defined such that 85% of the institutions perform a test with this or a higher frequency. Consequently 15% of the institutions (three) do perform a check with a frequency $\leq f_{85\%}$. An 'X' in the $f_{50\%}$ ($f_{85\%}$) column means that at least 50% (15%) of the institutions do not perform this check as part of a QC-programme.

[2] As presented in this report

[3] The values of the tolerance levels in NCS Report 8 are to be considered desirable during standard use of a medical linear accelerator.

description	*para-graph*	*current practice*		*minimum requirements*		*NCS Report 8*	
		$f_{50\%}$	$f_{85\%}$	*minimum frequency*	*action level*	*recom-mended frequency*	*tolerance level*
Correspondence X-light							
correspondence X-light	3.	2W	M	M (3M)	±2mm	2W	±2mm or ±1%
Flatness							
photons	4.1	M	M	A	±3%	A	±3%
electrons	4.2	M	3M	A	±3%	M	±3%
Symmetry							
photons	4.1	M	M	M	±3%	M	±3%
electrons	4.2	M	3M	M	±3%	M	±3%
Beam energy							
photons	5.1	3M	A	A	±2%	A	±0.005 or ±1%
electrons	5.2	3M	A	6M	±2mm	3M	±2mm
Absolute dosimetry							
photons	6.1	W	W	2W	±2%	W	±2%
electrons	6.2	W	2W	2W	±2%	W	±2%
Wedge filter							
wedge filter	7.	M	X	3M	±2%	M	±1%
Dose monitoring system							
reproducibility	8.1	X	X	-	-	A	±0.5%
linearity	8.2	X	X	-	-	A	±1%
dose rate effect	8.3	X	X	-	-	A	±2%
stability	8.4	X	X	-	-	A	±2%
gantry angle	8.5	X	X	A	3%	A	3%
Arc therapy							
arc therapy	9.	X	X	3M	±5% or 3°	M	±5% or 3°
Leakage radiation							
leakage radiation	10.	X	X	A	-	-	-

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