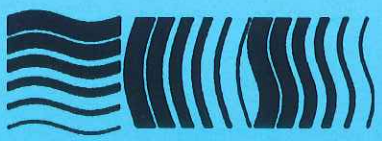
Quality Control (QC) of Simulators and CT scanners and some basic QC methods for Treatment Planning Systems

Current practice and minimum requirements

NEDERLANDSE COMMISSIE VOOR STRALINGSDOSIMETRIE

Report 11 of the Netherlands Commission on Radiation Dosimetry



Netherlands Commission on Radiation Dosimetry
Task Group Quality Control Radiotherapy
September 1997

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Note:
This report is partially superseded by NCS report 15, Quality assurance of 3-D treatment planning systems for external photon and electron beams.
Please note that a new version should occur before 2020.

Netherlands Commission on Radiation Dosimetry
Revision of NCS reports
December April 2014

Quality Control (QC) of Simulators and CT scanners and some basic QC methods for Treatment Planning Systems

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Preface

The Nederlandse Commissie voor Stralingsdosimetrie (NCS, Netherlands Commission on Radiation Dosimetry) was officially established on 3 September 1982 with the aim of promoting the appropriate use of dosimetry of ionizing radiation both for scientific research and practical applications. The NCS is chaired by a board of scientists, installed upon the suggestion of the supporting societies, including the Nederlandse Vereniging voor Radiotherapie en Oncologie (Netherlands Society for Radiotherapy and Oncology), the Nederlandse Vereniging voor Klinische Fysica (Netherlands Society for Clinical Physics), the Nederlandse Vereniging voor Radiobiologie (Netherlands Society for Radiobiology), the Nederlandse Vereniging voor Stralingshygiëne (Netherlands Society for Radiological Protection), the Nederlandse Vereniging voor Biofysica (Netherlands Society for Biophysics), the Nederlandse Vereniging van Radiologisch Laboranten (Netherlands Society of Radiographers and Radiological Technologists) and the Ministry of Health, Welfare and Sports. To pursue its aims the NCS accomplishes the following tasks: participation in dosimetry standardisation and promotion of dosimetry intercomparisons, drafting of dosimetry protocols, collection and evaluation of physical data related to dosimetry. Furthermore the commission shall maintain or establish links with national and international organisations concerned with ionizing radiation and promulgate information on new developments in the field of radiation dosimetry.

QUALITY CONTROL (QC) OF SIMULATORS AND CT SCANNERS AND SOME BASIC QC METHODS FOR TREATMENT PLANNING SYSTEMS CURRENT PRACTICE AND MINIMUM REQUIREMENTS

In 1996 the Netherlands Commission on Radiation Dosimetry (NCS) issued Report no. 9, entitled "Quality Control of Medical Linear Accelerators, current practice and minimum requirements". This report contains the results of a study which aims to investigate current quality control programs in all radiotherapy institutes in the Netherlands and recommends generally adopted minimum requirements on quality control. The present report contains the additional results, concerning quality control of simulators, CT scanners and some basic QC methods for treatment planning systems. The studies were performed by a project group established on the initiative of the Netherlands Society on Clinical Physics and supported by the Netherlands Commission on Radiation Dosimetry, the Netherlands Society for Radiotherapy and Oncology, the Dutch Society for Radiographers, the University Hospital Utrecht and the Netherlands Cancer Institute with financial support of the Dutch Ministry of Health, Welfare and Sports.

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Summary

An extensive questionnaire on quality control (QC) procedures of simulators and computed tomography (CT) scanners was completed by all (21) radiotherapy institutions in The Netherlands. In addition a questionnaire on basic methods for QC procedures for treatment planning systems was completed by the radiotherapy centres.

Large variations were observed in time dedicated to QC for simulators, i.e., between 2 and 20 hours per month per simulator. A great similarity exists in the frequency distributions of checks on the most important mechanical parameters of simulators and linear accelerators. Among the participating institutions, 40% indicated that they did not have any QC protocol with respect to the imaging system of the simulator.

Most of the CT scanners used for treatment planning are located at the departments of diagnostic radiology within the same institute. For this reason less than half the number of radiotherapy departments perform QC of CT scanners. The emphasis of the QC checks is put on the accuracy of image reconstruction and on the value of CT numbers.

The 21 radiotherapy institutions operate 11 different types of treatment planning systems. QC of treatment planning systems after acceptance for clinical use is mainly aimed at reproducibility of the equipment. A thorough acceptance testing and commissioning of treatment planning systems is not included in the present report. This aspect will be dealt with by a new subcommittee of the NCS. QC aspects in this report are mainly related to QC of the: integrity of software and data files, actual and implemented beam data, digitiser and plotter, transfer of CT data and correlation of CT numbers with electron densities. Finally, some patient specific procedures are presented.

The data obtained from the questionnaires were compared with recommendations given in five national and international reports on QC of simulators and CT scanners and with four reports on QC of treatment planning systems. From these combined data a set of minimum requirements has been formulated, specific for the situation in the Netherlands. The present report contains over 30 test procedures including test frequencies and action levels.

Introduction

This report presents the results of the second and third phase 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 for Radiotherapy and Oncology (NVRO), 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 consensus in the different quality control (QC) programmes and to recommend national guidelines on QC procedures in radiotherapy.

Three 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 NCS Report 9 'Quality Control of Medical Linear Accelerators, Current practice and minimum requirements'[12]. In the present report the results of phase 2 and 3 are shown and a set of **minimum** requirements has been proposed, suitable for all radiotherapy institutions in The Netherlands. These requirements are characterised by a minimum test frequency and, if relevant, an action level. Additional controls are recommended after major repair. The minimum requirements have been established after weighting the recommendations found in the literature and the results of the questionnaire.

The action level has been defined in NCS Report 9 as follows: Whenever an action level is reached, it is essential that appropriate actions are taken. However, some deviations are not easily and quickly corrected; some may be almost impossible or very expensive to restore. On very few occasions, it might be justified to use the radiation equipment clinically, when an action level has been exceeded. Such a delicate decision can only be taken after careful consideration by the responsible physicist, with the knowledge of the clinicians and radiographers. For example, the preparation of curative treatments demand a high stability of the simulator 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 the preparation for palliative posterior-anterior or anterior-posterior irradiation 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.

In order to formulate minimum guidelines for QC concerning simulators, CT scanners, equipment which combine both functions and treatment planning systems, we were guided by the currently employed protocols in The Netherlands and various published reports on quality assurance[1, 5, 7, 9, 10, 14, 15, 19]. Contrary to the situation for linear accelerators, not many directives have been published concerning QC of simulators, CT scanners and treatment planning systems. This does, however, not imply that the establishment of a good QC programme

for simulators or CT scanners is of less importance than for accelerators. Especially, when it comes to geometrical conditions, similar or even more stringent tolerances should be imposed on simulators and CT scanners, since deviations in geometrical position during the localisation will directly lead to systematic errors during the treatment of the patient. In a similar way, deviations in the treatment planning process will lead to systematic errors in the treatment.

To obtain knowledge of the QC protocols for simulators and CT scanners as well as that employed in practise for QC of treatment planning systems currently employed in The Netherlands, questionnaires have been sent to all 21 Dutch radiotherapy institutions. The questionnaires concerned methods, frequencies, time required for the tests, tolerance levels as well as the training of the personnel performing these measurements. The data gathered from the responses from the radiotherapy centres are compared with national and international recommendations.

Results

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

- Methods for quality control of simulators and simulator tables largely resemble those of accelerators and accelerator tables. The reader is referred to NCS Report 8[11] for a more detailed description of these methods.

- In many reports on QC of simulators, CT scanners and treatment planning systems the concept of 'tolerance level' is used. Sometimes the definition is very close to the definition of the action level as defined above, but often, a tolerance level is not well defined and serves merely as a guideline for limits in QC or acceptance testing procedures. All performance descriptors not specifically defined as action levels will therefore be addressed in the current report as tolerance levels.

- In the tables representing an intercomparison of recommended tolerance levels, the action levels presented by Brahme et al.[1] and Van Dyk and Mah[19] are always given, followed by their tolerance levels in brackets.

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

- Some departments may have more than 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 most frequent test frequencies are indicated.

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

- Various checks may be implicit. For example, since door interlocks (and many other devices) are used daily, it may be assumed that the associated malfunctioning will be detected immediately. However, the histograms only represent frequencies of tests that are part of a *formal* routine.

1. Simulators

In The Netherlands 36 simulators are presently in operation at the 21 radiotherapy institutions. The majority of these simulators are associated with teletherapy equipment. A few institutions have a separate simulator for brachytherapy facilities. The number of simulations/localisations performed monthly on a single simulator varies between 70 and 237. The average is about 130. Figure 1 presents the (machine) time spent monthly on QC of simulators in The Netherlands (6.5 hours per month on average).

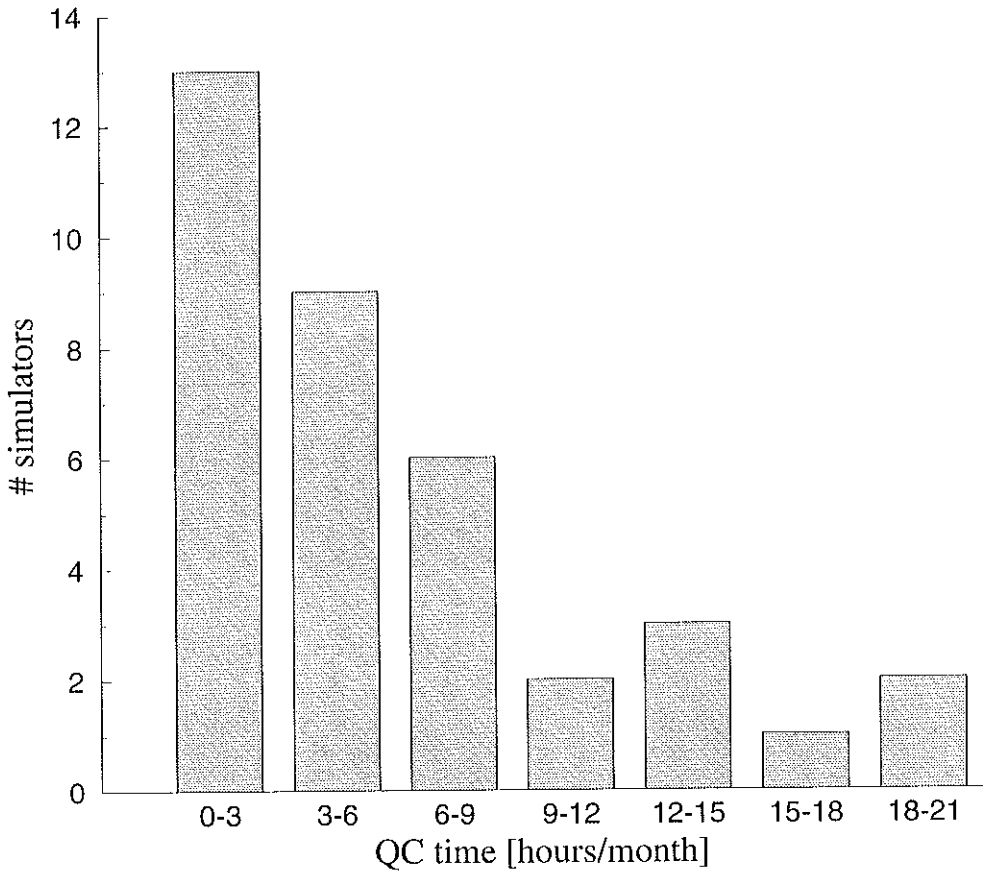

Figure 1: Frequency distribution of the time spent monthly on QC of simulators in The Netherlands

Comparison of recommendations

Five reports containing recommendations concerning QC of simulators have been investigated. The suggestions in the reports of Brahme et al.[1], Kutcher et al. (Report of the AAPM Radiation Therapy Committee Task Group 40)[7], McCullough and Earle[9] and Suntaralingam[14]

should be regarded as general guidelines for QC of simulators. The report of Van Dyk and Mah[19] stresses the importance of an elaborated QC programme and gives some examples of QC tests and their corresponding frequency of performance as used on three simulators at the Princess Margaret Hospital. Brahme et al.[1] and Van Dyk and Mah[19] distinguish between a tolerance level and an action level. In the AAPM report actions are required only when a parameter exceeds a tolerance level. Therefore, in that report, tolerance levels are identical to action levels. Suntaralingam[14] lists a number of specific parameters to be checked together with the frequency of testing. Tolerance levels are not stated, although references are made to tolerance levels given by a working group of the British Institute of Radiology[2].

1.1 Safety systems

Like medical accelerators most simulators are equipped with a number of interlock systems that should protect the patient, personnel and the simulator against unallowed actions. The correct functioning of these interlocks can easily be verified.

inter-institutional survey

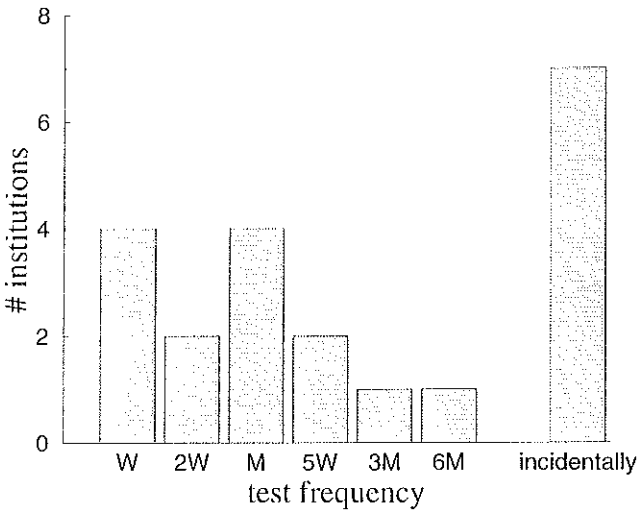

Figure 2: Frequency distribution of the checks on warning lights and acoustic signals

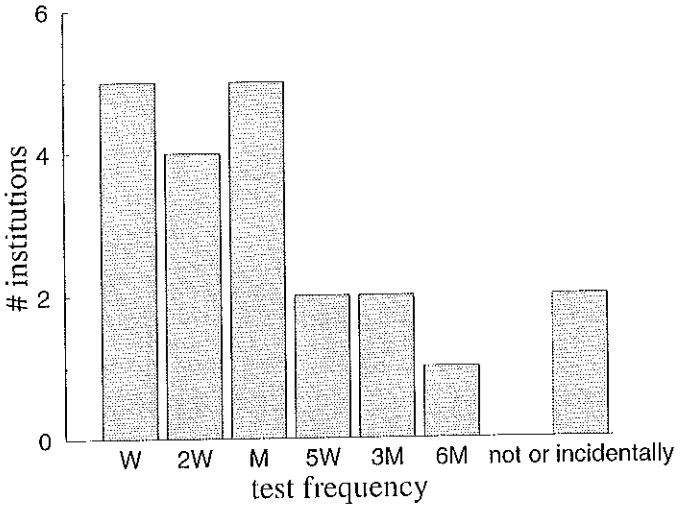

Figure 3: Frequency distribution of the checks on the anti-collision interlocks

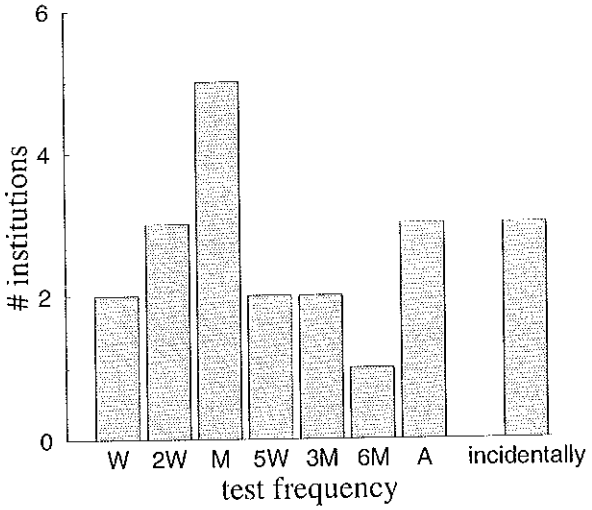

Figure 4: Frequency distribution of the checks on end-course cutoffs

comparison of recommendations

Table 1: Intercomparison of recommended test frequencies for safety systems

report	*recommendations*
AAPM	monthly checks of warning lights and anti-collision systems
Brahme et al.	weekly checks of the general mechanical integrity and safety
McCullough and Earle	a complete repetition of the acceptance test at one-year intervals
Suntaralingam	weekly checks of door interlocks, emergency switches and anti-collision systems
Van Dyk and Mah	daily checks of warning lights, door interlocks, emergency switches, dead-man switches and anti-collision systems

minimum requirements

test frequency		*warning lights*	:	3M
,,	,,	*anti-collision*	:	M
,,	,,	*end-course*	:	A

1.2 Mechanical parameters

Many QC tests of the mechanical aspects of simulators are similar to those of linear accelerators. Consequently, the minimum requirements described in NCS Report 9[11] have influenced the minimum requirements proposed in this chapter. For a description of the methods used we refer to NCS Report 8[11]. The radial motion of the x-ray tube requires some additional tests. Unless the simulator is used to produce CT images, no specific mechanical tolerances on the image intensifier motions are demanded, except nominal range and speed specifications[1].

1.2.1 Cross-hair position

inter-institutional survey

All institutions regularly verify the correspondence between the mechanical axis of the collimator and the light beam. 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 always taken at the isocentre. This is different from a similar test for linear accelerators, where the absence of the image intensifier also permits measurements at the ground level. One institution verifies the projection of the X-ray beam axis with a little lead sphere placed at the isocentre. Figure 5 displays the variations in test frequencies among all institutions. The tolerances applied in these centres vary between 1 and 2 mm for the diameter of the circle which encompasses all centres of cross-hair projections on the table at isocentric height during collimator rotation.

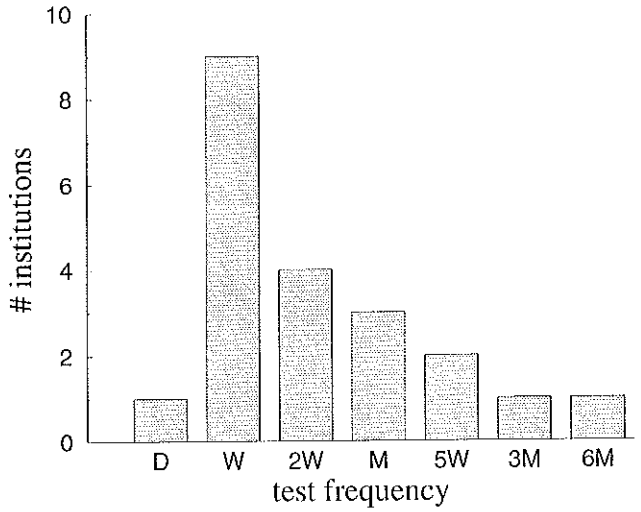

Figure 5: Frequency distribution of the checks of the correspondence between the mechanical axis of the collimator and the light beam axis

comparison of recommendations

Table 2: Intercomparison of recommended test frequency and tolerance level for positioning of the cross-hair

report	*frequency*	*tolerance level*
AAPM	M	Ø 2mm
Brahme et al.	W	Ø 1mm; (Ø 0.5mm)
McCullough and Earle		Ø 1mm
Suntaralingam	W	-
Van Dyk and Mah	D	Ø 1mm; (Ø 0.5mm)

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 test should therefore be performed with a minimum frequency of at least once per month.

1.2.2 Mechanical isocentre position

inter-institutional survey

The isocentre is the centre of the smallest sphere, through which the axis of the beam passes in all conditions. This position is normally determined by examining the projection of the cross-hair under different gantry angles. As shown in Figure 6, 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 the location of the isocentre is also of great importance for identifying deviations in the laser alignment system, the optical distance indicator and treatment table scales.

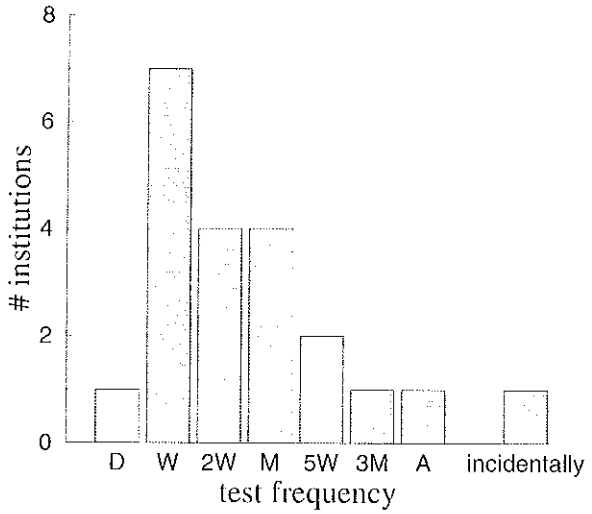

Figure 6: Frequency distribution of checks on the position of the mechanical isocentre

comparison of recommendations

Table 3: Intercomparison of recommended test frequencies and tolerance levels for positioning of the mechanical isocentre

report	*frequency*	*tolerance level*
AAPM	A	Ø 2mm
Brahme et al.	A	Ø 2mm; (Ø 1mm)
McCullough and Earle	A	Ø 3mm
Suntaralingam	M	-
Van Dyk and Mah	-	-

minimum requirements

test frequency	:	A
action level	:	Ø 2mm

Changes in major mechanical tolerances are unlikely to take place on a weekly or monthly basis; therefore, a minimum test frequency of once a year is suggested. The deviation of the isocentre with gantry rotation is the most critical mechanical tolerance for simulators[9]; therefore it is suggested that the change in position of the cross-hair projection at isocentric height at the gantry angles 0° and 180° is at least checked with an annual frequency.

1.2.3 Laser beam alignment

inter-institutional survey

A complete laser beam alignment test consists of two checks. First, the coincidence between the point of intersection of all lasers with the isocentre should be checked. Figure 7 shows the frequencies of this test, which is carried out at 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 sixteen institutions (see Figure 8) periodically check the beam alignment. An often used method is to compare the projection of the lasers with reference markers on the floor and walls or using a spirit level. Variations up to 0.5° are tolerated.

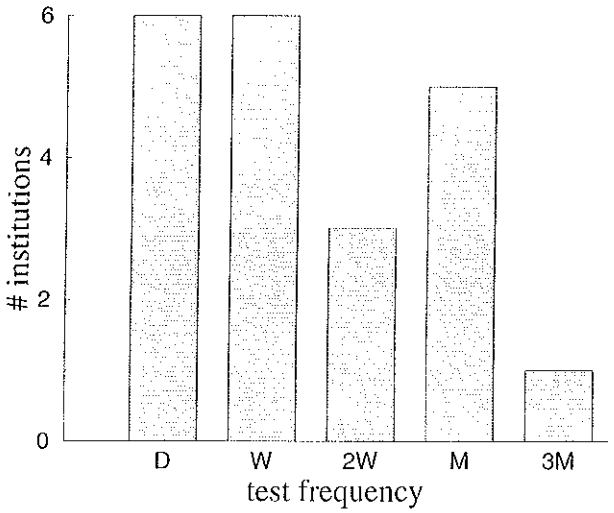

Figure 7: Frequency distribution of the positioning check of the lasers

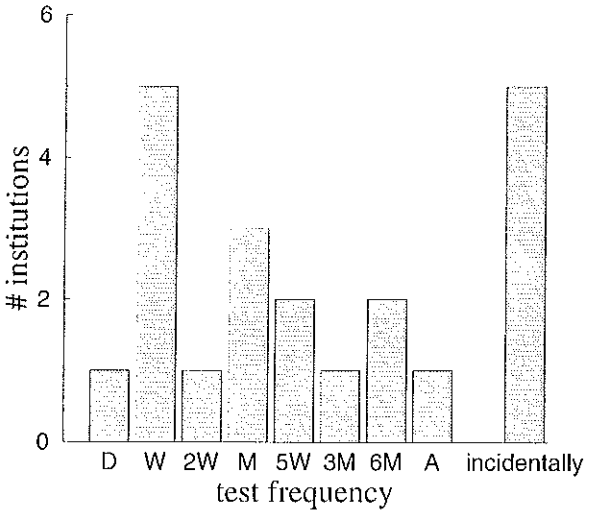

Figure 8: Frequency distribution of the alignment check of the lasers

comparison of recommendations

Table 4: Intercomparison of recommended test frequency and tolerance level for positioning and alignment of the lasers

report	*frequency*	*tolerance level*
AAPM	D	2mm
Brahme et al.	W	1mm; (0.5mm)
McCullough and Earle	W	-
Suntaralingam	W	-
Van Dyk and Mah	D	-

minimum requirements

test frequency	:	M
action level	:	$\pm$2mm at the isocentre

The laser alignment is of great importance and a minimum test frequency of the laser system of once a 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 to be preferred if not both tests are performed, although the second method has the advantage that the laser beams are checked on being horizontal and vertical.

1.2.4 Optical distance indicator

inter-institutional survey

All institutions check the accuracy of the optical light indicator at a regular basis, as can be seen in Figure 9. The test frequencies range from daily to once every three months. The tolerance levels vary from 1 mm up to 2 mm over their working range (SSD = 100 cm $\pm$ 20 cm).

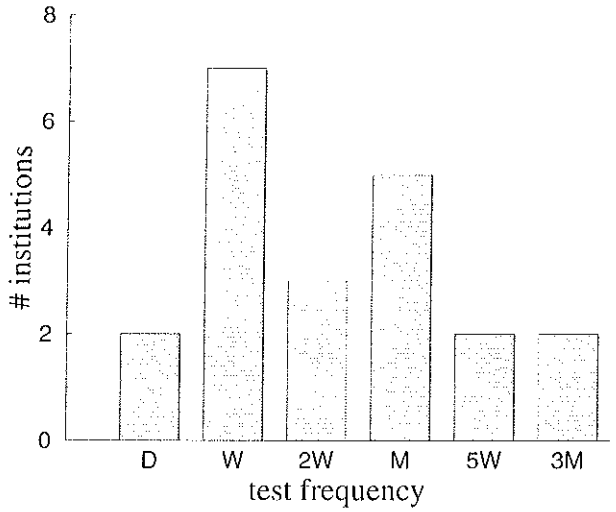

Figure 9: Frequency distribution of checks of the accuracy of the optical distance indicator

comparison of recommendations

Table 5: Intercomparison of recommended test frequency and tolerance level for the optical distance indicator calibration

report	*frequency*	*tolerance level*
AAPM	D	2mm
Brahme et al.	W	2mm; (1mm)
McCullough and Earle	W	2mm
Suntaralingam	-	-
Van Dyk and Mah	D	-

minimum requirements

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

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

1.2.5 Geometrical field size indication

inter-institutional survey

This check is usually carried out by projecting various light fields at graph paper (with 1-mm graduations) at a horizontal plane at isocentric height. The test is generally not limited to measuring 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 10. The tolerance levels range from 1 mm to 2 mm per delineator wire. One institution checks the field size indication in the fluoroscopic mode, with the use of a lead ruler. Six institutions perform additional checks regarding the position of the field collimators.

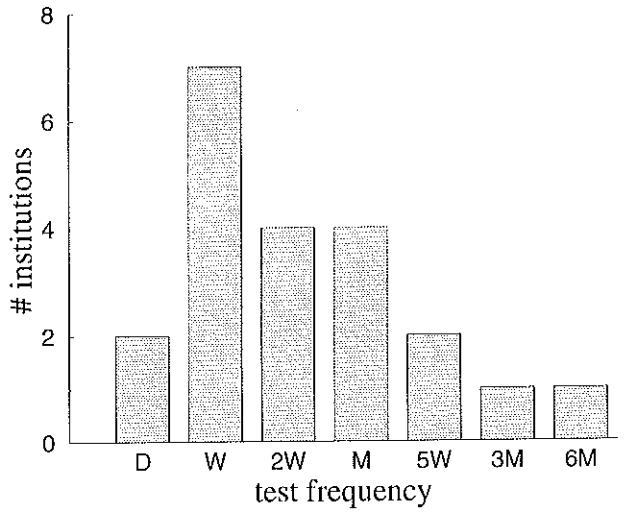

Figure 10: Frequency distribution of the checks of the accuracy of the position of the lead or tungsten wires (size)

comparison of recommendations

Table 6: Intercomparison of recommended test frequency and tolerance level for the field size calibration

report	*frequency*	*tolerance level*
AAPM	W	2mm
Brahme et al.	W	1mm; (0.5mm)
McCullough and Earle	W	1mm for field sizes $\leq$ 15cm$\times$15cm ; 2mm for field sizes $>$ 15cm$\times$15cm
Suntaralingam	W	-
Van Dyk and Mah	D	-

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 field sizes. More extended tests are suggested which include checks on symmetry, parallelism and rectangularity of the delineator wires. These tests should be performed at least once a year.

1.2.6 Treatment table

isocentric rotation

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 an isocentric rotation. Tolerance levels are expressed as the diameter of the circle which encompasses all centres of the cross-hair projections during table rotation at isocentric height. Figure 11 shows the test frequencies of this check in the various institutions.

inter-institutional survey

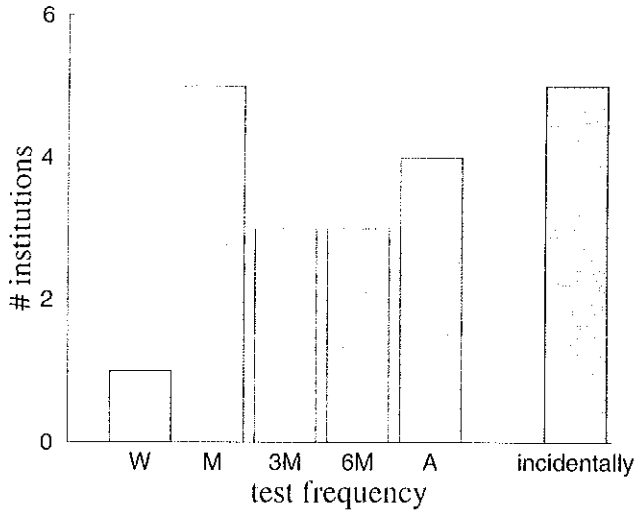

Figure 11: Frequency distribution of checks on the isocentric rotation of the table around the plateau axis.

comparison of recommendations

Table 7: Intercomparison of recommended test frequency and tolerance level at isocentric height for the isocentric rotation test

report	*frequency*	*tolerance level*
AAPM	A	2mm
Brahme et al.	3M (X-ray)	2mm; (2mm)
McCullough and Earle	A	2mm
Suntaralingam	6M	-
Van Dyk and Mah	-	2mm; (2mm)

minimum requirements

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

A test, at two different table heights, with a 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.

slope of the table top

inter-institutional survey

The treatment table top should be horizontal. Figure 12 shows the frequency distribution of the check to what extent this condition is met. The tolerance levels vary between 2.5 mm/m and 3.6 mm/m (i.e. 0.14° up to 0.2°). The slope of the table top is mostly checked by means of a spirit level.

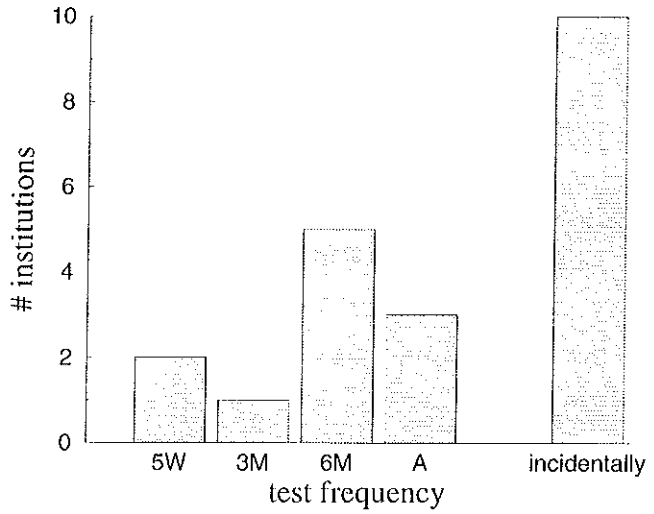

Figure 12: Frequency distribution of the checks of the slope of the table top

comparison of recommendations

Table 8: Intercomparison of recommended test frequency and tolerance level of the check of the slope of the table top

report	*frequency*	*tolerance level*
AAPM	A	2mm
Brahme et al.	-	-
McCullough and Earle	A	-
Suntaralingam	6M	-
Van Dyk and Mah	-	-

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 action levels are 5.0 mm/m and 2.5 mm/m for longitudinal and lateral directions, respectively.

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 13 shows the different test frequencies of this check among the institutions. Most institutions apply a tolerance level varying between 1 mm and 2 mm horizontal shift.

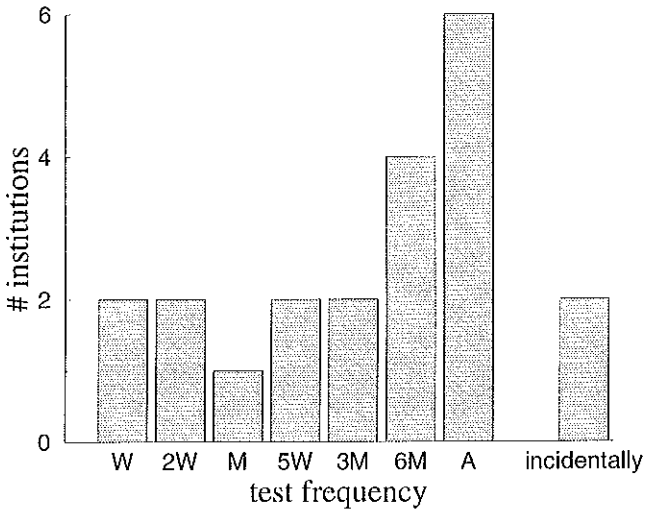

Figure 13: Frequency distribution of the checks of the horizontal shift during vertical motion

comparison of recommendations

Table 9: Intercomparison of recommended test frequency and tolerance level of the checks of the horizontal shift during vertical motion

report	*frequency*	*tolerance level*
AAPM	-	-
Brahme et al.	-	-
McCullough and Earle	A	1mm
Suntaralingam	6M	-
Van Dyk and Mah	-	2mm; (1mm)

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, at different isocentric table rotation angles. 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 axis is as vertical as possible. This could be checked using a plumb line.

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. Differences exist in the specified weights, weight distributions and the resulting displacement of the table top end. Consequently, comparison of the tolerance levels is not possible, but range from an allowable table sag from 4 mm to 10 mm. The test frequencies can, however, be compared and are listed in Figure 14.

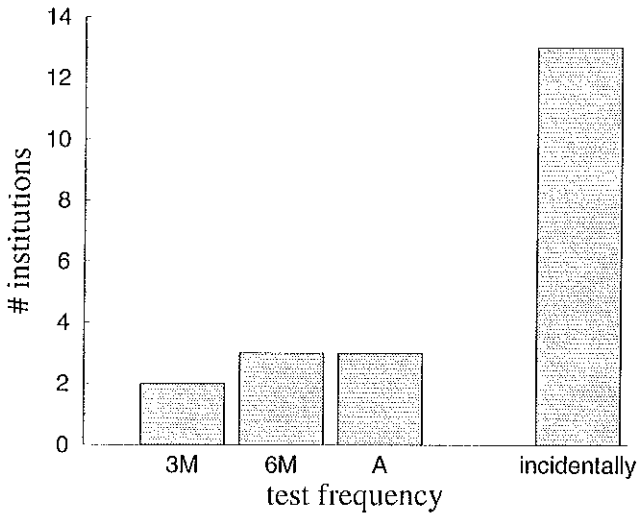

Figure 14: Frequency distribution of the checks of the table top rigidity

comparison of recommendations

Table 10: Intercomparison of recommended test frequency and tolerance level for rigidity control of the treatment table

report	*frequency*	*tolerance level*
AAPM	-	-
Brahme et al.	-	-
McCullough and Earle	A	-
Suntaralingam	6M	-
Van Dyk and Mah	-	3mm; (2mm)

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 approximately 50 kg is placed at the end of the table top, when it is in its outermost longitudinal or lateral position. The table top sag may not exceed 5.0 mm or 2.5 mm in the longitudinal or lateral directions respectively. Special attention should be focussed on the sag of the Melinex, tolerances of mechanical bearings and twists of the treatment table, although no action levels are suggested here.

scales on the treatment table

inter-institutional survey

In Figure 15 test frequencies of the checks of the electrical and mechanical readings are represented.

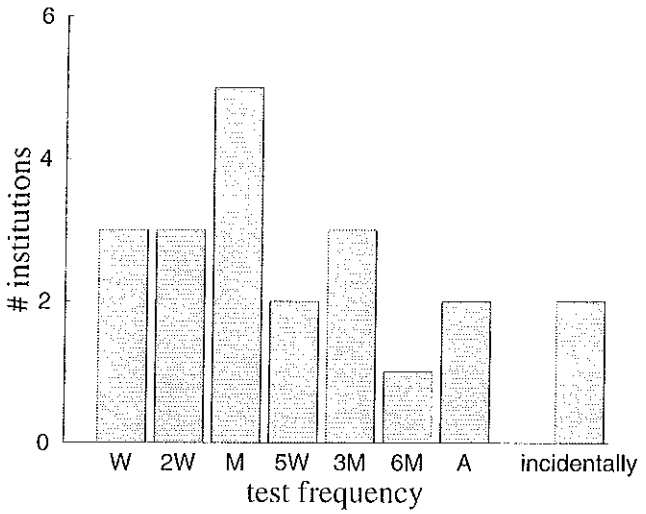

Figure 15: Frequency distribution of the checks of the correspondence between table position readings at the treatment control panel, the mechanical scale readings and the actual position

comparison of recommendations

Table 11: Intercomparison of recommended test frequencies and tolerance levels for the checks of the scales on the treatment table

report	*frequency*	*tolerance level*
AAPM	-	-
Brahme et al.	W	-
McCullough and Earle	A	-
Suntaralingam	W	-
Van Dyk and Mah	-	-

minimum requirements

test frequency	:	A (M)
action level	:	$\pm$2mm or $\pm1°$

This test serves to check the linearity of the various scales on the treatment table rather than calibrating 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 relative to a reference mark, then a minimum frequency of once a month is suggested.

1.2.7 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 held against a true surface at the radiation head verifying the readings at gantry angles of 0°, 90°, 180° and 270°. Figure 16 shows the test frequencies of this check. The tolerance levels range from 0.5° to 1°, although one institution reported to apply a tolerance level of 0.2°.

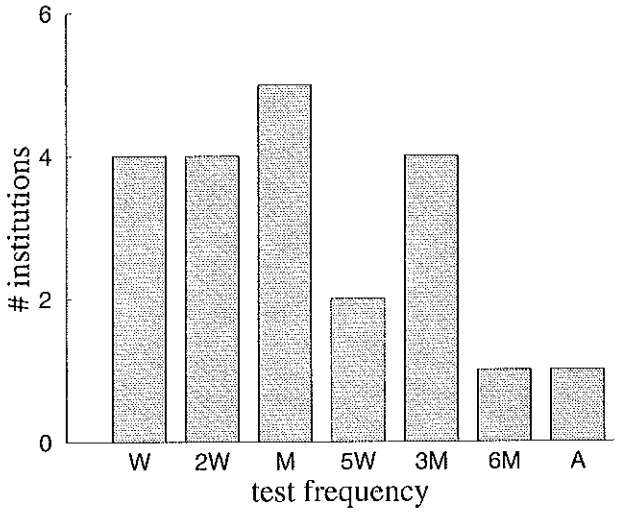

Figure 16: Frequency distribution of the checks of the correspondence between gantry angle selected at the treatment control panel and the actual position

comparison of recommendations

Table 12: Intercomparison of recommended test frequencies and tolerance levels for the check of the gantry angle readings

report	*frequency*	*tolerance level*
AAPM	A	2°
Brahme et al.	3M	2°; (1°)
McCullough and Earle	A	-
Suntaralingam	W	-
Van Dyk and Mah	-	-

minimum requirements

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

Both mechanical and electrical readings of the gantry angle can be checked in the four major directions with a spirit level, but also the projection of the cross-hair at the walls can 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.

1.2.8 Collimator rotation

inter-institutional survey

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 delineator wires should be either horizontally or vertically. Assuming that both readings do not deviate in the same way, it suffices to check the mechanical and electrical reading on conformity. Figure 17 shows the frequencies of the control of the electrical readings. Similar tolerance levels as applied for the gantry angle check are applied.

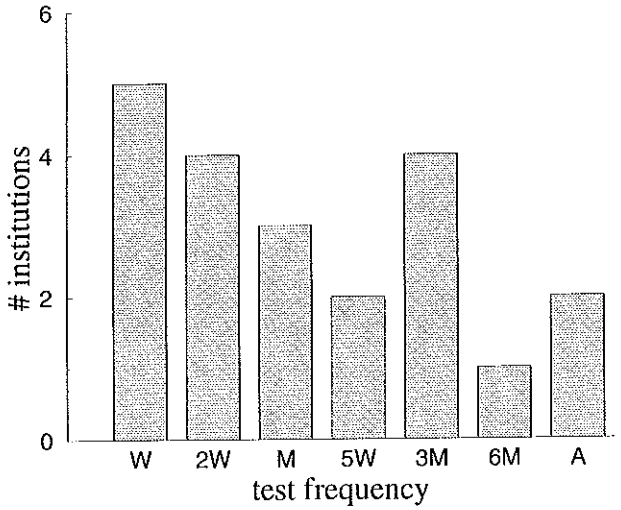

Figure 17: Frequency distribution of the checks of the correspondence between collimator angle selected at the treatment control panel and the actual position

comparison of recommendations

Table 13: Intercomparison of recommended test frequencies and tolerance levels for the check of the collimator angle readings

report	*frequency*	*tolerance level*
AAPM	A	2°
Brahme et al.	3M	2°; (1°)
McCullough and Earle	A	-
Suntaralingam	W	-
Van Dyk and Mah	-	-

minimum requirements

test frequency	:	6M
action level	:	±1°

A minimum frequency of twice a year is suggested for the test of the mechanical and electrical collimator readings.

1.2.9 Source-axis translation

inter-institutional survey

Most simulators have the capability to adjust the source-axis distance (SAD), which is different from the situation with linear accelerators. Figure 18 shows the frequency distribution of checks which verify the accuracy of the electrical and mechanical readings indicating the SAD. It should also be checked whether the radiation head moves in the correct radial way with variation of the SAD (e.g. vertically at a gantry angle of 0°). This is done by checking the cross-hair intersection wander during radial motion. The different test frequencies of this check are represented in Figure 19.

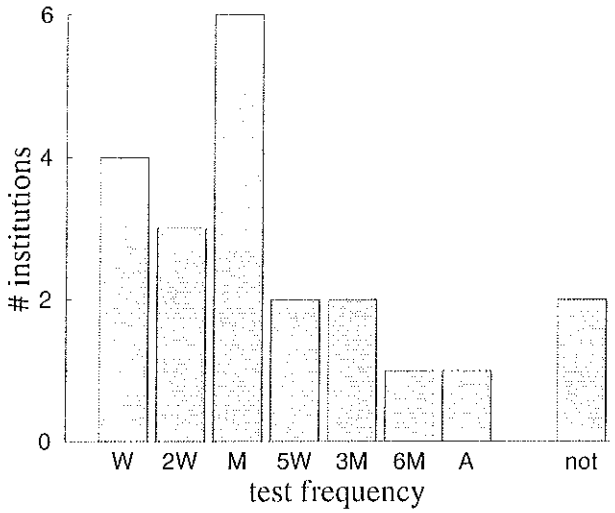

Figure 18: Frequency distribution of the checks of the correspondence between SAD readings at the treatment control panel, the mechanical scale readings and the actual position

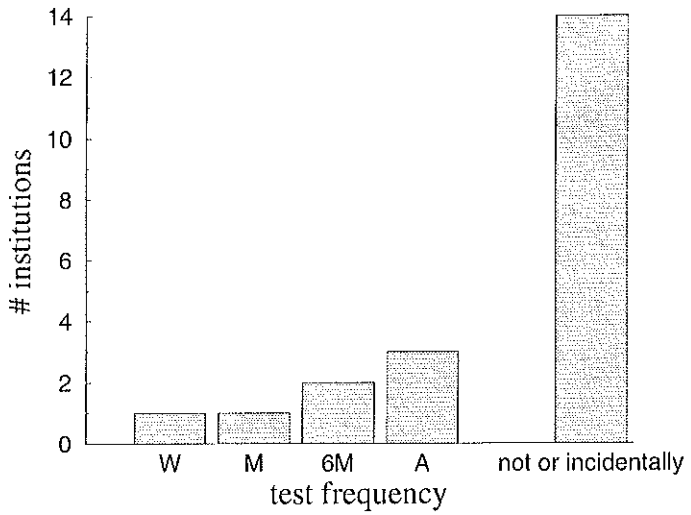

Figure 19: Frequency distribution of the checks of the radial radiation head movement

comparison of recommendations

Table 14: Intercomparison of recommended test frequencies and tolerance levels for the check of the SAD readings

report	*frequency*	*tolerance level*
AAPM	-	-
Brahme et al.	3M	1mm (digital) 2mm (mechanical); (1mm)
McCullough and Earle	A	1mm
Suntaralingam	W	-
Van Dyk and Mah	-	1mm; (1mm)

minimum requirements

test frequency	:	6M
action level	:	±2mm (scales)
		Ø2mm (cross-hair projection)

It is suggested that the accuracy of the scales indicating the source-axis distance is checked at least twice per year, together with the movement of the cross-hair projection at the isocentre during variation of the source-axis distance.

1.3 Correspondence between light field and radiation field

inter-institutional survey

The primary goal of this test is to check the size and location of the light field in relation to the size and location of the radiation field. Two different methods are observed here:

- Fifteen 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.
- Eleven institutions perform this check in the fluoroscopic mode, using lead rulers and test phantoms.

Consequently, five institutions use both methods. The tolerance levels range from 1 mm to 2 mm per delineator wire for small field sizes up to 1% of the field length or width for larger field sizes. Figure 20 represents the different test frequencies of the radiation field-light field correspondence check. All but four institutions perform this check only at a gantry angle of 0°. Fourteen institutions check the correspondence between the light field and radiation field at several field sizes. When using the film method, different x-ray images can easily be evaluated when a lattice was accurately placed on the film.

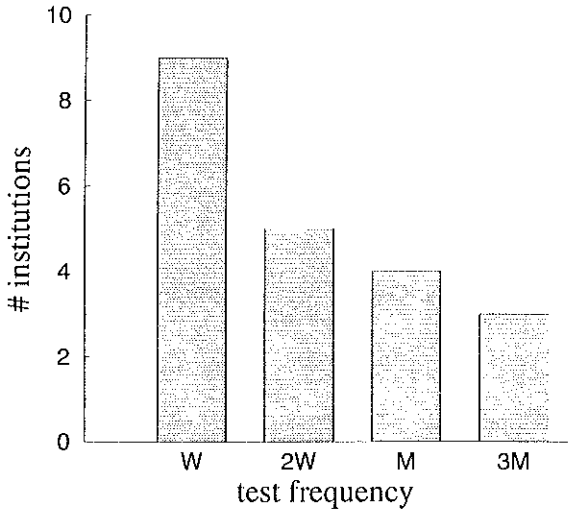

Figure 20: Frequency distribution of the checks on the correspondence between light field and the radiation field

comparison of recommendations

Table 15: Intercomparison of recommended test frequencies and tolerance levels of the check of the correspondence between light field and radiation field

report	*frequency*	*tolerance level*
AAPM	M	2mm or 1%
Brahme et al.	W	1mm; (0.5mm)
McCullough and Earle	A	-
Suntaralingam	W	-
Van Dyk and Mah	D	-

minimum requirements

test frequency	:	M minimal one field size 3M minimal three field sizes
action level	:	$\pm$ 2 mm for each boundary

It is suggested that the size and location of the photon fields and light fields are 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. For a detailed description of the test procedure, the reader is referred to paragraph 5.1 of the NCS Report 8[11]. Unlike for megavoltage beams, where the measurements are performed at a depth of 5 cm water, all measurements should be performed at the isocenter using film.

1.4 Image formation and image detection

Distances between the focal spot and the image receptor of 100 cm Up to 170 cm are common in radiotherapy resulting in low intensities at the image intensifier. Furthermore, simulation often involves lateral or oblique views through large body thicknesses. Both differences confirm the idea that the imaging system of the simulator must be checked at least as often as in diagnostic radiology.

inter-institutional survey

Many institutions do not regularly check the accuracy of the kVp indicator as can be seen in Figure 21. Similar results have been obtained for checks regarding the linearity of exposure,

the half value-layer and the spatial and contrast resolution. In several institutions these checks are performed by the manufacturer.

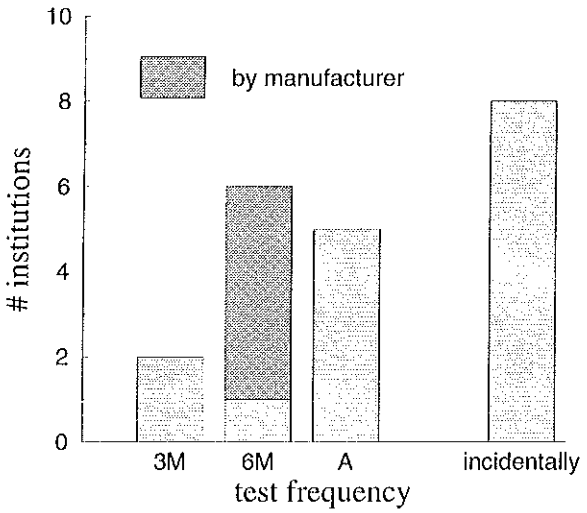

Figure 21: Distribution of the frequencies at which the peak kilovoltage is measured

comparison of recommendations

Table 16: Intercomparison of recommended test frequencies of the imaging system

report	*recommendations*
AAPM	annual checks of the exposure rate, table top exposure with fluoroscopy, kVp and mAs calibration and high and low contrast resolution
Brahme et al.	quarterly checks of the image intensifier focus (using a mesh test tool)
McCullough and Earle	annual checks of the focal spot size, kVp indicator, timer, mAs linearity, mA and mAs repeatability mR/mAs and half value-layer (filtration); for the fluoroscopic mode the following parameters may be monitored: maximum output levels, resolution (wire mesh), low-contrast resolution, distortion and focus and TV system leg
Suntaralingam	6-monthly checks on beam quality (kVp), beam intensity (mR/mAs) and high and low contrast resolution
Van Dyk and Mah	6-monthly checks on exposure reproducibility, half value-layer, kVp indicator, automatic exposure termination, fluoroscopic resolution, fluoroscopic exposure rate

minimum requirements

test frequency : A

It is suggested that at least once a year the imaging system is checked for the following parameters:

- low-contrast resolution
- spatial resolution
- kVp and mAs (action level: ±5%)

The first two parameters can be determined using a contrast detail (CD) phantom as described by Thijssen et al.[16]. A quantitative analysis can be carried out using an image quality figure (IQF) as described in the same paper. IQF is defined as the sum of the products

of depth (C_i) and diameter (D_i) of the correctly recorded 15 just visible spots along the CD line in the phantom:

$$\text{IQF} = \sum_i C_i \cdot D_i$$

Van der Meer[18] however stated recently that a more objective method using a modulation transfer function (MTF) and noise phantom should be applied. This method is based on the determination of a signal to noise ratio spectrum using a step of 1 mm Cu and quantifying the film result with a film scanner (a Lumiscan model 100 will provide adequate accuracy). At present, this technique is still at an experimental stage.

The tube voltage can be determined using the method described in chapter 2 of a report on quality control of equipment used in diagnostic radiology[13]. This report recommends the use of electronic devices for non-invasive measurement of the tube voltage. For acceptance and status tests, the accuracy of this tube voltage should be measured for all relevant settings. For constancy tests the measurements can be restricted to the most commonly applied tube voltage. For determination of the tube current exposure time product (mAs) the report[13] recommends a device appropriate for measurements in the range of 0-900 mAs and an accuracy and precision of 5%.

2. CT scanners

In the past decade, the use of patient information derived using CT scanners has become very important in radiotherapy treatment planning. The primary use of CT scanners is for delineation of tissues, abnormalities, and neoplasms; i.e. for the definition of the target volume and organs at risk. Many radiation therapy departments do not have their own CT scanner. Usually, CT scanners are housed in departments of diagnostic radiology, often within other institutions. Consequently, most QC checks are performed by these departments or are performed by the manufacturer. Only a few radiotherapy institutions in The Netherlands perform their own QC of CT scanners. At the time of the questionnaire, some departments indicated that QC measures specifically directed to the use of treatment planning objectives were not performed, but that an appropriate QC programme was under design. It turned out that most radiotherapy departments are not familiar with QC programmes performed by the manufacturer or by the department that performs the checks.

2.1 Mechanical parameters

2.1.1 Couch and insert

inter-institutional survey

Diagnostic imaging is usually performed with curved couch tops. To emulate the therapy machine couch top, a flat insert is required. It is essential that the insert is placed horizontally and that the combination of couch with insert is rigid and the mechanical tolerances are reduced to a minimum. Figure 22 shows the frequency distribution of the check that verifies the slope of the insert. This check is mostly performed using the positioning lights or by examining the scan of a test phantom. Only a few institutions periodically check the couch and insert on rigidity and mechanical tolerances.

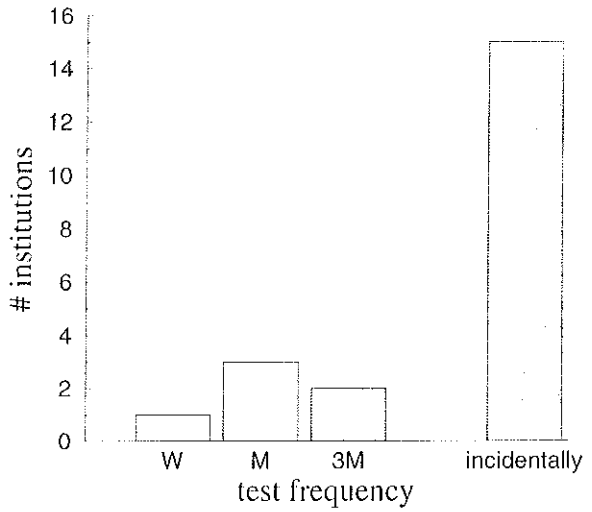

Figure 22: Frequency distribution of the check of the slope of the insert of CT scanners

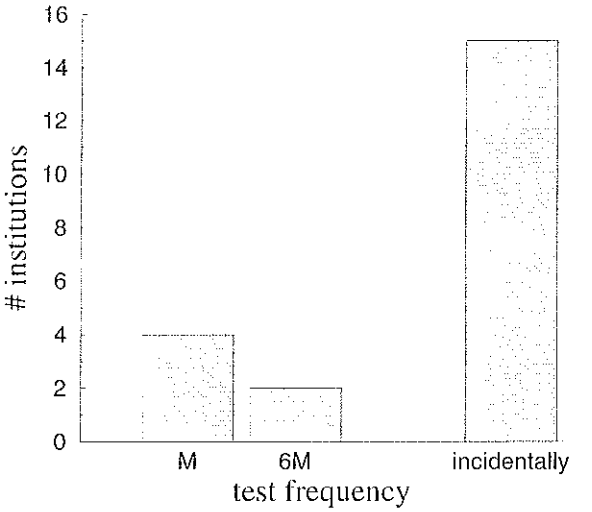

Figure 23: Frequency distribution of the rigidity test of the couch and insert

comparison of recommendations

Specific recommendations concerning the QC of the couch and insert have not been found in the literature.

minimum requirements

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

It is suggested that the slope of the flat insert is tested at least once a year. It is important that the insert cannot easily be shifted. Action levels up to 5.0 mm/m can be accepted. Table tops used at electron accelerators and simulators are generally more rigid than most couches of CT scanners. Consequently, the rigidity of the couches of the CT scanners cannot be subjected to tests where loads of 50 kg or more are placed at the end of the table top. Each institution has developed its own procedure for testing the rigidity of the couch and insert. As a result, action levels are not suggested here, but it is recommended that the rigidity of the couch and insert should be checked at least once a year.

2.1.2 Lasers

inter-institutional survey

CT scanners commonly used in radiotherapy treatment planning are equipped with a (laser) light positioning system mounted on the walls of the CT suite. In Figure 24 the different test frequencies are represented.

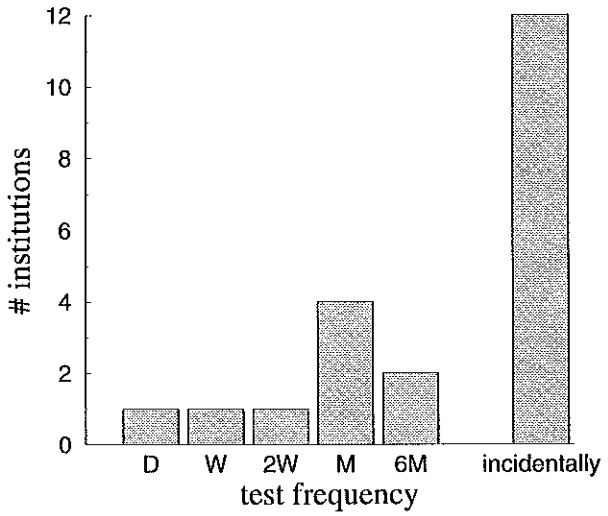

Figure 24: Frequency distribution of the checks of the (laser) light positioning system

comparison of recommendations

Table 17: Intercomparison of recommended test frequency and tolerance level for the light positioning system

report	*frequency*	*tolerance level*
AAPM	D	-
Brahme et al.	-[1]	-
Ten Haken et al.	-[1]	-
Van Dyk and Mah	-[1]	-

minimum requirements

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

2.2 CT numbers and image reconstruction

inter-institutional survey

For radiotherapy applications special requirements with respect to the accuracy of the CT numbers (if used in the treatment planning system) and geometrical accuracy are needed. A test phantom can be very useful to simultaneously check a variety of parameters. Such a test phantom is mostly cylindrically shaped and has several sections with different, well-known, electron densities.

Several performance parameters could be checked with a test phantom[10] including:

precision : the standard deviation of the CT numbers obtained by scanning a uniform material (e.g. a water phantom);

contrast : the contrast scale (cm^{-1}/CT number), defined by the ratio of the difference in linear X-ray attenuation coefficient of two materials and the difference in the corresponding CT numbers;

linearity : verification of the linear relationship between the CT numbers and the linear attenuation coefficients;

[1]these tests are mentioned and recommended to be part of a QC programme but test frequencies and/or action levels are not suggested

spatial resolution : resolving power of the scanner, obtained by scanning a series of low (high) contrast elements of decreasing diameter.

geometrical accuracy : precise imaging of patient or phantom geometries in three dimensions.

Figures 25-29 show the different test frequencies of the above described parameters. Three institutions perform additional tests regarding the influence of high Z-materials on the quality of the scan and the dependence of the size of the scanned object on the resulting CT numbers. If the table insert is provided with rods, made of specific materials, which are placed at fixed distances, then the geometrical accuracy and basic CT number evaluation of the scanner can be easily tested at every patient, as one centre showed.

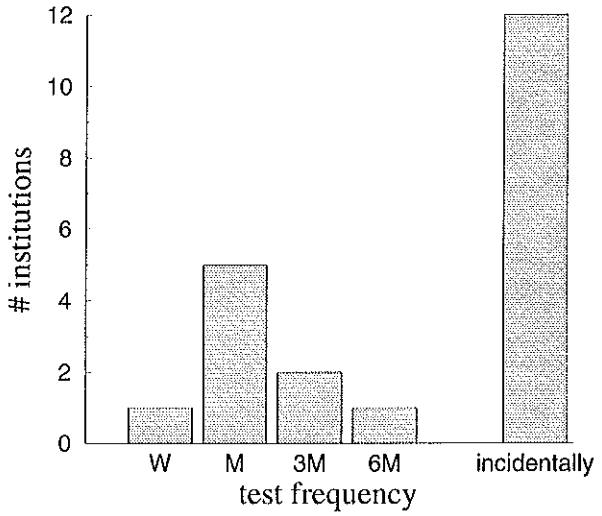

Figure 25: Frequency distribution of the checks on CT numbers of a uniform material

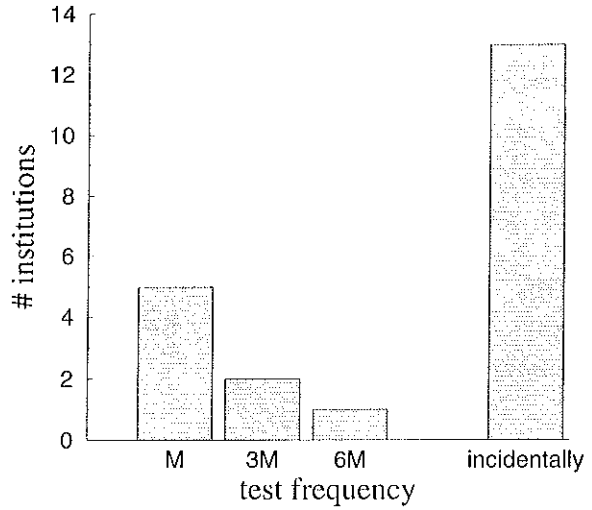

Figure 26: Frequency distribution of the checks on the contrast scale

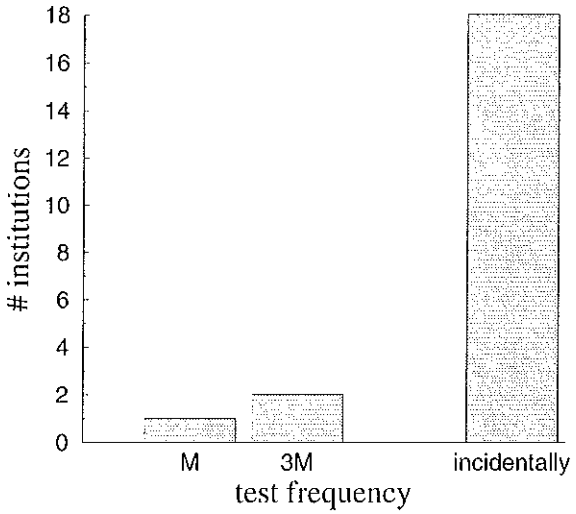

Figure 27: Frequency distribution of the checks on the relationship between the linear attenuation coefficients and the CT numbers

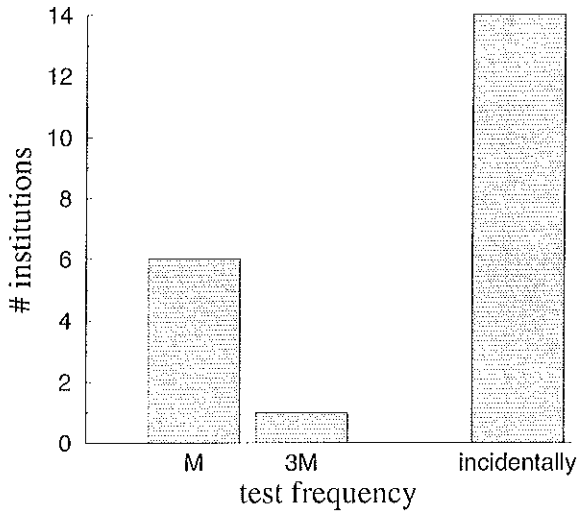

Figure 28: Frequency distribution of the checks on the spatial resolution

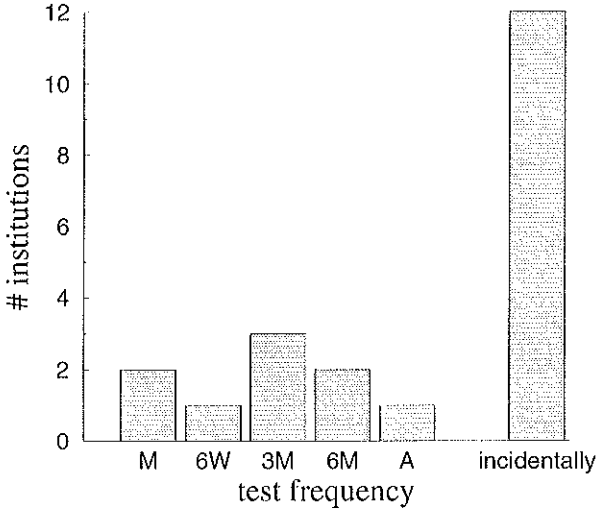

Figure 29: Frequency distribution of the checks on the geometrical accuracy

comparison of recommendations

Table 18: Intercomparison of recommended tests concerning CT numbers and image reconstruction

report	*recommendations*
AAPM	annual checks of the correlation of CT numbers with electron densities and variation of the CT numbers with position and phantom size; in addition, the CT scanner should be checked for image quality and other parameters described in the QA protocol provided by the manufacturer
Brahme et al.	ongoing quality control including monitoring changes in CT number normalisation, uniformity and scan noise
Ten Haken et al.	a reasonable QC programme might include: - checks on the sensitivity of the CT number for changes in the position and scan environment - checks of the correlation of CT numbers with electron densities - checks on the geometrical accuracy of the CT scans as used in the treatment planning system - reviewing procedures that may already be in place within the diagnostic radiology department
Van Dyk and Mah	every 3-6 months checks with regard to the geometric accuracy of the scans in the treatment planning system and to the correlation of CT numbers with electron densities

minimum requirements

test frequency : 6M

It is suggested that the CT scanner is checked for geometrical accuracy at least once every six months. By scanning a phantom, entering the data into the treatment planning computer, and plotting the external contours, it is important to evaluate not only the geometrical accuracy of the scanner, but also the transfer into the treatment planning system. If the CT numbers of the scan are utilised as means of correcting for inhomogeneities, the correlation between CT number and electron density should be verified at least every six months.

3. Treatment planning systems

The use of computers in treatment planning has been of great importance for the last two and a half decades. The enormous increase in the calculation power of computers in combination with technological advancement in diagnostic and therapy equipment during this period resulted in more complex treatment techniques. These developments coincide with an increased dependence on the accuracy and reliability of these systems. This is certainly true for the current 3D systems, where a large number CT, MR or other diagnostic images are used. Distortions in these geometries may often be very difficult to recognise for the user. It becomes therefore increasingly important to check the complete planning system periodically. This includes CT interface, digitiser and plotter, for consistency after the planning system has passed all acceptance and commissioning procedures. In this chapter we will only discuss treatment planning systems used for teletherapy, but most of the tests reviewed here will also be applicable to brachytherapy planning systems. Special tests for QA (including acceptance and commissioning) of 3D planning systems will be the subject of further investigation. A comprehensive report is presently being developed by Task Group 53 of the AAPM and a subcommittee of the NCS.

Comparison of recommendations

Until now, very few reports deal in detail with aspects of quality assurance of treatment planning systems and even less reports discuss routine quality control after the treatment planning system has been accepted. However, a small number of working groups in different countries is currently evaluating their specific national requirements and/or drafting a document[8]. One of the most comprehensive reports concerning commissioning and quality assurance of treatment planning computers has been published by Van Dyk et al.[20]. Detailed guidelines are provided regarding sources of uncertainties, suggested tolerance levels, initial system checks and repeated system checks.

Curran and Starkschall[3] have presented a procedure to verify that the dose planning system is performing adequately. Special attention is paid to algorithm verification, accuracy of input/output devices and accuracy and integrity of treatment unit data sets.

Another comprehensive report on quality assurance of treatment planning systems has recently been published by the Institute of Physics and Engineering in Medicine[6]. The primary aim of this document is not to set out a full quality assurance system for computer planning, but to concentrate primarily on requirements for commissioning and ongoing performance testing. The last chapter is completely devoted to suggestions for a scheme of tests to ensure that the planning system continues to perform satisfactorily.

In some countries, e.g. the Czech Republic, proposals have been developed regarding quality assurance of treatment planning systems. The Czech QA programme is divided into four basic groups: commissioning tests, tests after a new software release, tests after entering new beam data and regular tests to check the stability of the system performance.

Inter-institutional survey

Due to the limited information available in the literature, it could be expected that the QC of treatment planning systems is not uniform. In order to obtain insight in the currently employed QC protocols for treatment planning systems in The Netherlands, a questionnaire has been sent to all radiotherapy institutions early 1996. In Figure 30 a representation is given of the treatment planning systems currently in use in The Netherlands together with the year of implementation of the latest software release. Most systems used are not older than three years. The manufacturers of the Philips OSS system and the Target I system have stopped to release new versions of their software since 1988. Because new releases are often implemented every one or two years, a thorough acceptance testing and commissioning is of extreme importance. Such a programme includes performing initial system checks regarding hardware and beam algorithms, investigating sources of uncertainties and also user training. It should be noticed, however, that in this report we are primarily concerned with quality control, i.e. reproducibility checks after the treatment planning system has been accepted for clinical use.

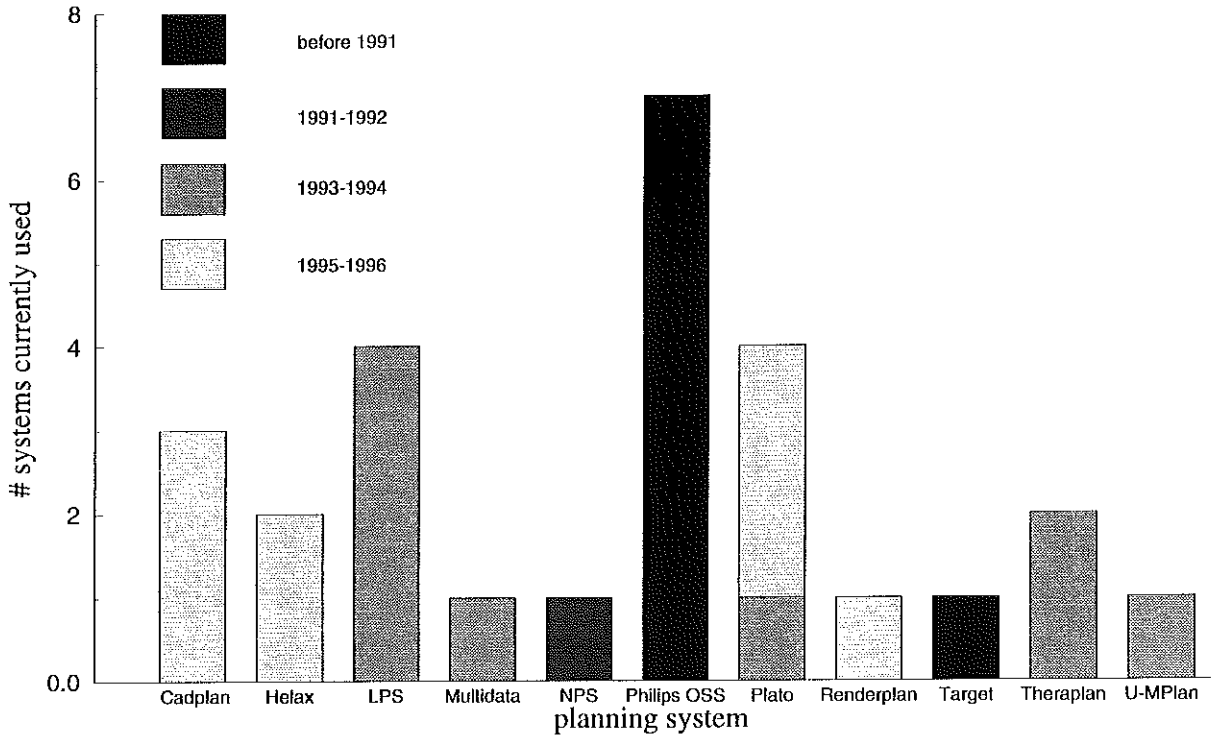

Figure 30: Distribution of different therapy planning systems used in 1996 in The Netherlands with the year of implementation of the latest release

Dahlin et al.[4] have listed some basic requirements for system documentation of any treatment planning computer. They suggested that the source code should be provided for testing and software adjustments. It turned out, however, with the exception of Theraplan and Renderplan, that none of the manufacturers gives access to the source code. This will be partially due to the fact that modern planning software is extremely complex and therefore not suitable for adjustments made by users. The Helax system provides string files which could be used for customising layout and user interface.

3.1 Integrity of software and data files

inter-institutional survey

Once the treatment planning system has been accepted for clinical use, on-going QA must be performed to ensure the integrity of the data files and the reproducibility of the calculations. A sophisticated reproducibility check is to run a command file which initiates a binary comparison of all software and data files. A disadvantage of this method is that all files need to be stored double. Until now, four institutions perform such checks, although one institution has limited this check only to the monitor unit calculation program. Mostly these checks are automatically performed every day or week in an overnight test run.

A slightly less complicated test is done by performing a mathematical operation to verify that the software and data files have not been altered without verification. For example, a simple check might be the sum of the digits of all the numbers in the data file. A different outcome implies that the data file has been changed and needs to be reviewed. Such checksum tests are performed periodically in six institutions and one institution indicated that such a procedure will be developed.

Finally, it is useful to repeat the calculation of a number of treatment plans performed during the commissioning of the system. The outcome of the tests can be compared to reference values. Contrary to the binary comparison test and the checksum test described before, repeating single treatment plans can not completely guarantee the integrity of all the software and data files. On the other hand, these tests need not to be limited to the calculation process only and can enclose more stages in the planning process. Another advantage is, that the outcome of a recalculation of a standard plan will also be dependent on the correct functioning of the hardware (e.g. the floating point processor). Seven institutions periodically reconstruct standard treatment plans with frequencies varying between once a month and once every year. In all but two cases the complete planning process is tested with hand imported input. Two institutions use input data stored on file; consequently, differences will not be found between the calculated output and the reference output, since in this case only the calculation process is tested.

Table 19: Intercomparison of recommended tests concerning the integrity of software and data files

report	*recommendations*
Curran and Starkschall	• checksum verification every month of all data files • monthly comparison of isodose plots for each calculation path
Czech proposal	• annual reconstruction of beam data: comparison of isodose curves, dose profiles and depth dose curves • annual reconstruction of non-stored fields: comparison of isodose curves and output factor calculation • annual reconstruction of modified fields: comparison of isodose curves, percentage depth dose diagrams and output factor calculation • reconstruction of standard set of plans: measured and calculated, every year, and calculated compared to the original plan, once per month
IPEM	• a simple memory function test whenever the equipment is activated • monthly comparison of machine data against hard copy • monthly calculation of reference and non-reference field sizes • three-monthly calculation of a standard plan to check: focus source distance variation, oblique incidence, wedge calculation, collimator rotation (45°, internal inhomogeneity, off-axis calculation and beam blocking) • monthly check of the function and accuracy of: change of field position, change of field weight, change of field size and hot-spot and point-dose calculations • three-monthly check of a number of patient-type plans
Van Dyk et al.	• six-monthly tests of point doses (rectangular and irregular fields), lateral profiles (open and wedge), inhomogeneities (air slab and bone-like slab) • six monthly tests of summation algorithms: equally weighted, unequally weighted and wedged fields; a three-field technique • six monthly tests of machine settings: single field with wedges, trays and/or shields; 4 field, linac, unequally weighted

minimum requirements

test frequency : 6M

Checksum routines have proven to be very effective and useful tools for identifying corrupt data and command files. Once a checksum application has been developed, it is easily implemented and can automatically be started in an overnight test run. It is therefore advised to use checksum routines to check the integrity of all data and command files. The repetition of the calculation of a number of selected treatment plans will be of additional value. It should be noted that during the commissioning of a new system and after software changes it is essential that an elaborated set of different configurations should be planned. Besides tests concerning the integrity of the data and software files, it is essential that the correct functioning of the hardware is periodically checked. One institution implemented a procedure in which a large matrix is inverted. The product of the original matrix with the calculated inverse matrix should subsequently yield the identity.

3.2 Beam data; actual and implemented

inter-institutional survey

It is very important that the implemented beam data in the treatment planning system are in agreement with the actual beam data. Van Bree et al.[17] showed that differences between the actual beam data and the beam data implemented in the planning systems resulted in incorrect dose calculations in several centres in The Netherlands. Ten institutions periodically check all relevant parameters on consistency and explicitly compare these parameters with those implemented in the treatment planning system. The test frequencies vary from monthly (only wedge factors) to once every two year (including profiles and PDDs). Three institutions indicated that these comparisons were occasionally performed.

intercomparison of recommendations

Table 20: Intercomparison of recommended tests concerning the implemented beam parameters

report	*recommendations*
Curran and Starkschall	annual verification of input and output data for each treatment unit
Czech proposal	-
IPEM	-
Van Dyk et al.	-

minimum requirements

test frequency : 2A

It is suggested that the actual reference data set for the accelerator is in compliance with the actual data set implemented in the treatment planning system with a test frequency of at least once every two years.

3.3 Digitiser and plotter

inter-institutional survey

About half the number of institutions periodically check the accuracy of the digitiser and plotter, although different methods are applied. A few centres test these devices by entering a number of specified shapes of known dimensions (e.g. squares) using the digitiser, and by plotting these shapes. Tolerances between 1 mm and 2 mm are usually accepted. Other institutions check the digitiser and plotter as a separate part within the reconstruction of a reference treatment plan. The final plot will then be checked against a reference plot. Different test frequencies occur, varying from once a week to once a year.

intercomparison of recommendations

Table 21: Intercomparison of recommended tests concerning the digitiser and plotter

report	*recommendations*
Curran and Starkschall	monthly checks of digitiser and plotter, accuracies $<$ 1mm
Czech proposal	monthly checks of digitiser and plotter, action level: 1% (1mm) and 2% (3mm) respectively
IPEM	digitiser : • a simple check of system function and scaling each time the equipment is used (such as by digitising three fixed points) • every six months a detailed test to check resolution and linearity (by digitising a variable grid) plotter: • a simple plot of a standard pattern every week for regular use and every month otherwise
Van Dyk et al.	weekly checks of digitiser and plotter (square contour)

minimum requirements

test frequency	:	6M
action level	:	2mm

It is suggested that the accuracy of the digitiser and plotter are checked at least twice a year. This is easily tested by entering and plotting a simple contour (rectangle). The plot can be compared with the initial contour. Deviations more than 2mm may not be accepted for the combined check result.

3.4 Transfer of CT data and correlation of CT numbers with electron densities

inter-institutional survey

The accuracy of data transfer from CT scanner to the planning system can easily be checked using standard CT scans which are filed. However, most centres performing data transfer checks prefer to combine these checks with a complete phantom scan. In this way a complete set of CT data is evaluated after the data are entered into the planning system. The different test frequencies are shown in Figure 31. One institution uses special markers in the insert of the couch with well known density,to check the geometrical accuracy and CT-number conversion at each transfer. Six institutions perform additional checks regarding the correlation of CT numbers with electron densities.

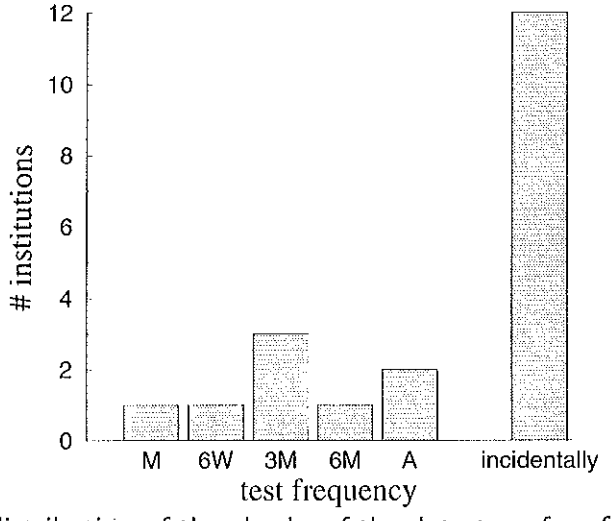

Figure 31: Frequency distribution of the checks of the data transfer of the CT scanner to the planning system

intercomparison of recommendations

Table 22: Intercomparison of recommended tests concerning the transfer of data files to the planning system

report	*recommendations*
Curran and Starkschall	three-monthly checks associated with the transfer from CT scanner to planning system
Czech proposal	daily transfer of CT slices into the planning system annual tissue density calculation (action level: 3%)
IPEM	monthly transfer check of a filed standard CT scan
Van Dyk et al.	three-monthly checks associated with the transfer from CT to planning system

minimum requirements

test frequency : 6M

It is suggested that the data transfer from CT scanner to the planning system is checked at least once every six months. By scanning a phantom and entering the data into the treatment planning computer, both the geometrical accuracy and CT number values can be checked together with the data transfer. If the CT numbers of the scan are utilised as a mean of correcting for inhomogeneities, the correlation between CT number and electron density should be verified at least every six months.

3.5 Patient specific procedures

inter-institutional survey

Almost every centre performs additional checks to verify the correctness of each treatment plan to ensure that each patient is planned accurately, but a lot of variation in different procedures can be observed (see Table 23). Nine institutions use a separate MU calculation program to verify a point dose of each (photon) beam at given machine settings. Two institutions indicated that such a program was under development. The machine settings are mostly checked by a (second) radiographer, although clinical physicists and their assistants and radiotherapists are often involved. Especially when discrepancies occur, the clinical physicist will often be consulted. Besides the routine checks on all treatment plans, six centres indicated that the clinical physicist checks a few treatment plans per month from start to finish randomly. None of the centres indicated that the relative dose distributions were (manually) checked.

Table 23: Summary of different procedures used to check individual treatment plans

	checks including recalculation of monitor units		*checks on input parameters only*
	manual recalculation	MU calculation program	
all new treatment plans	3 centres	7 centres	4 centres
random selection and non standard plans	4 centres	2 centres	-

intercomparison of recommendations

Table 24: Intercomparison of recommended tests concerning the machine settings of the individual treatment plans

report	*recommendations*
Curran and Starkschall	-
Czech proposal	-
IPEM	'it is strongly recommended that there is a system in operation which checks by independent means the correct calculation of machine parameters for each patient'
Van Dyk et al.	independent (manual) checks of the machine settings and relative dose distributions done by an individual not involved in the first calculation

minimum requirements

test frequency	:	every treatment plan
action level	:	10%

It is strongly recommended that there is a system in operation which checks by independent means the correct monitor unit calculation for each patient.

4. Discussion

QC systems for simulators are generally less comprehensive than those for linear accelerators. This is partially due to the fact that simulators are not submitted to variations in delicate clinical dosimetric parameters such as field flatness, beam energy, wedge factors, but also because reports on QC of simulators are not regularly available at present. Regarding mechanical parameters, however, much resemblance exists between the test frequencies and tolerance levels for accelerators and simulators. It is remarkable that many parameters of the simulator table (e.g. slope, scales, isocentric rotation) are more often checked than the treatment table of the accelerator. In comparison to accelerators most simulators have the capability to adjust the source-axis distance. Most institutions, however, do not perform additional checks concerning this extra degree of freedom, like field size checks at different SADs or checks of the radial movement of the radiation head. Regarding suggestions for test methods for the different mechanical checks, where possible, we would like to refer to the analogous checks in NCS Report 8[11]. Regarding the imaging system, many centres indicated that no or little QC is performed.

The use of CT scanners for delineating target volumes and organs at risk in radiotherapy treatment planning is relatively new. Different specifications are required for the use of CT scanners regarding geometrical accuracy and accuracy of CT numbers. At this moment only a few centres regularly perform some QC checks on their CT scanner. A few centres indicated that appropriate protocols are in preparation. QC checks of CT scanners for radiotherapeutic purposes are generally not very time consuming. Apart from some mechanical checks, it often suffices to make a single scan of a test phantom with different segments and different electron densities.

It is remarkable that in 21 radiotherapy institutions 11 different treatment planning systems are being used. Only seven institutions perform an independent MU calculation on all new treatments. It is strongly recommended that there is a system in operation, which checks by independent means the MU calculation for each patient.

5. Conclusions

A comprehensive QC protocol for simulators, CT scanners is necessary to ensure that this equipment continues to perform according to a set of predefined standards. In this report a complete set of minimum guidelines has been suggested, specific for the situation in The Netherlands. The implementation of these guidelines would for many centres result in an extension of their currently applied QC protocol. This is especially true for the imaging system of simulators and CT scanners, since up to now, only a few institutions have developed a QC

programme regarding these systems. For treatment planning systems, the same conclusion is valid. Some basic methods are recommended in this report. More extensive tests will be described by a committee of the NCS specifically related to this subject.

Intercomparison of current practice and minimum requirements in The Netherlands

description	*para-graph*	*current practice*[1]		*minimum requirements*	
		$f_{50\%}$	$f_{85\%}$	*minimum frequency*	*action level*
Simulator					
warning lights	1.1	5W	X	3M	-
anti-collision	1.1	M	3M	M	-
end-course	1.1	5W	A	A	-
cross-hair	1.2.1	2W	5W	M	Ø2mm
mechanical isocentre	1.2.2	2W	5W	A	Ø2mm
lasers	1.2.3	W	M	M	±2mm
ODI	1.2.4	2W	5W	M	±2mm
field size indication	1.2.5	2W	5W	M	±2mm
isocentric rotation	1.2.6	6M	X	A	Ø2mm
slope table top	1.2.6	A	X	A	5mm/m
vertical movement	1.2.6	6M	A	A	2mm
rigidity table	1.2.6	X	X	A	5mm
scales table	1.2.6	M	A	A	±2mm, ±1°
scales gantry	1.2.7	M	3M	6M	±1°
scales collimator	1.2.8	M	3M	6M	±1°
source-axis translations	1.2.9	M	6M	6M	±2mm, Ø2mm
correspondence X-light	1.3	2W	M	M (3M)	±2mm
image forming and detection	1.4	A	X	A	-
CT scanner					
couch and insert	2.1.1	X	X	A	5mm/m
lasers	2.1.2	X	X	M	±2mm
CT numbers	2.2	X	X	6M	
image reconstruction	2.2	X	X	6M	
TPS					
file integrity	3.1	X	X	6M	-
beam data	3.2	2A	X	2A	-
digitiser and plotter	3.3	A	X	6M	2mm
CT transfer	3.4	X	X	6M	-
patient specific procedures	3.5	-	-	every patient	10%

[1] $f_{50\%}$ denotes the current median test frequency, while $f_{85\%}$ is the frequency defined such that 85% of the institutions performs 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.

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