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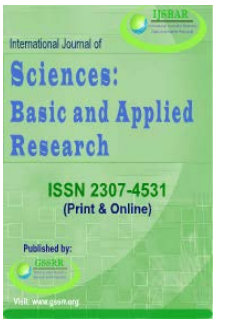

Quality Assurance and Performance Evaluation of an Elekta Linear Accelerator: Results From Over a Year QA Experience in Ghana.

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Abstract

This publication describes the first ever comprehensive Quality Assurance program of a linear accelerator to be developed and performed in Ghana, West Africa. Sweden Ghana Medical Centre has been operating an Elekta synergy Platform Linear accelerator over the past years. The QA programs, results and performance evaluations are presented and analyzed over a twenty (20) month operational period. The checks include daily, weekly, monthly, and yearly quality assurance procedures as well as patient specific quality assurance in accordance with the centre's policy. The results of the evaluation show reproducibility in all quality assurance procedures with an average photon and electron daily radiation output constancy of (-0.8%±1.2) and (-1.38±0.96) of expected values respectively. The weekly and monthly radiation output constancy checks had an average deviation of 0.53%±0.4 and a maximum deviation of 1.9% for photons and an average of 1.5%±0.4 and maximum of 2.6% for electrons. Yearly dosimetry quality assurance was within 0.8% of calibrated values at commissioning whiles safety and mechanical/optical checks were functional and within set limits respectively.

Keywords: Action level; QA procedure; Quality assurance; Radiation constancy check; Tolerance levels.

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1. Introduction

Sweden Ghana Medical Centre (SGMC) is the first and only cancer Center in Ghana and among the very few in West Africa to operate a linear accelerator (dual energy photon: 6 and 15 MV and a range of electron beams: 6, 10 and 15 MeV). The Center covers a full range of cancer specialties and utilizes modern state-of-the- art equipment and treatment techniques to provide a 3-dimensional (3D) conformal radiation treatment. With no national or regional published quality assurance (QA) guidelines to follow, it sometimes becomes very difficult adopting an international protocol that suits our local settings. It should also be noted that it may be unrealistic to carry out some of the tests described in international protocols [1, 2, 3, 4] at local centres, either because major investments (human or technical resources) are required, or because the parameter being tested is not available, or not in clinical use. It is also the responsibility of a qualified medical physicist to apply these recommendations in a suitable manner [5]. The delivery of accurate prescribed doses to patients is one of the cardinal objectives of radiotherapy treatment. To achieve this, it is imperative that effective and efficient quality control (QC) procedures are put in place in every country where radiotherapy machines are operated. The operation of an effective QC checks will ensure that the machine characteristics do not deviate significantly from their baseline values acquired at the time of acceptance and commissioning. This document is intended to provide Ghanaian and to a larger extend West African radiotherapy centers with streamlined Linac procedures for carrying out requisite QA tests to suit our local conditions. Specific QA protocols have been adapted from the American Association of Physicists in Medicine Task Group (AAPM TG) number 40, AAPM TG-45, AAPM TG-142, the European Society of Therapeutic Radiology and Oncology (ESTRO) and Elekta recommended user checks for the Linac at SGMC.

The success of every radiation therapy crucially depends on the accuracy with which the prescribed dose is delivered to the tumor volume; thus the dose delivered to the patient should be kept as close as possible to the prescribed dose. AAPM TG-40 recommends that the dose delivered to the patient be within ±5% of the prescribed dose [1] and ICRU 50 and 62 (-5%, +7%). Quality Assurance describes programs for checking the performance of radiotherapy equipment and for measuring the characteristics of the output from such equipment. It has a common basis in that it specifies the method of testing and test equipment, the parameters to be tested and the frequency of testing, the responsibilities of different members of staff, the baseline values and tolerances for these values, action levels and documentation guidelines. A clinical linear accelerator must in all circumstances function within the very narrow tolerances obtained at the time of acceptance testing [6]. It is therefore expected that a QA program designed specifically for an institution will meet those standards. For radiation oncology, the QA programs are to maintain the quality of patient care. The American College of Radiology (ACR) recommends a QA committee be formed with appropriate personnel (e.g., radiation oncologist, physicist, dosimetrist, therapist, engineer and administrator) [7]. Annual report should be prepared from individual QAs to include but not limited to dosimetry accuracy, mechanical accuracy, safety, imaging and special Procedures. Acceptance Testing Procedure (ATP) Standards are set as principles in testing the baseline for future dosimetric measurements in beam performance constancy. This verifies that the equipment is mechanically functional and operates within certain tolerances from absolute specified values. Three action levels (level1-Inspection, level 2-scheduled and level 3- immediate/stop treatment/corrective actions)

are set and followed according to their tolerance.

2. Materials and Methods

The proposed and adopted QA procedure included daily, weekly, monthly, and yearly checks, as well as individual treatment verifications. The daily QA includes delivery of 500 MU per photon energy as morning Linac warm-up and subsequent recording of photon and electron dosimetric values of the central axis at SSD of 100cm. The weekly QA includes measuring photon and electron dosimetric outputs and the wedge factors for photons. The monthly QA involves a complete and extensive measurement in terms of dosimetry, mechanical/optical and safety aspects. The annual QA includes a larger sampling of monthly QAs, beam characteristics, planned maintenance (PM), and analysis of all saved QA worksheet files. The individual treatment verification or "per patient" QA includes independent MU Calculations and a final check of all plans after the first treatment fraction according to the data in the record and verification system of the Linac. The procedures used are tailored to meet the needs of the department using published reports as a guide. All the QA tasks performed with their tolerances are summarized in Table 1. Based on all these checks, action levels are setted for all radiation constancy and mechanical checks.

2.1. Daily QA

The Linac output is checked on a daily basis prior to the first patient being treated. This test can be broadly classified into three groups: beam alignment, dosimetry and safety. A qualified medical physicist or radiotherapist usually performs these daily tests. Elekta recommends [8] that the Linac should be warmed up prior to daily use. A deviation of less than 3% is desirable for the dosimetric outputs using appropriate diodes. If any of these parameters are out of tolerance, they are reported to the medical physicists and the Linac clinical operation is suspended until the problem has been investigated further. With markings on the horizontal and vertical walls, it is ensured that the sagittal and lateral lasers align with the centre of the marks. The tolerances are 2 mm (that is ±1 mm) for both sets of lasers as well as the check for central axis rotation with collimator. The optical distance indicator (ODI) is also check at SSD with a tolerance of 2 mm. The door interlocks and audiovisual monitors are also part of the daily QA. The results of the daily check must all be within tolerances before the Linac is passed for clinical use.

2.2. Weekly QA

The dosimetric tests are performed with calibrated dosimetry equipment, a phantom and an ionization chamber. These tests are performed with a high level of accuracy to ensure that small variations are detected. The weekly test begins with the beam and mechanical alignment test, because deviations here can influence the dosimetry outcome. The output of the Linac is checked using a calibrated PTW Farmer chamber to ensure that 1 cGy/MU is delivered to the isocentre under specific reference conditions. A dose of 100 MU is delivered three times and the dosimeter readings are recorded using a PTW UNIDOS webline electrometer. The output in nC/MU is calculated as follows:

$$Output(nC/MU) = (mean\,\mathrm{Re}ading(nC) \times K_{TP} \times Cal.F \times K_{pol} \times K_{ele} \times K_s \times PCF)/MU \quad (1)$$

Where Cal.F is the calibration factor, (K_{pol}, K_{ele} and K_s) are the collection efficiency factors and mean Reading is the average of the electrometer readings. The phantom correction factor (PCF) is taken as 1.0 for a water equivalent phantom. K_{TP} is the temperature and pressure correction factor. Four different gantry angles (0°, 90°, 180°, and 270°) are chosen for each week's dosimetry measurements and it is important that the output is within ±3% of the reference dose. The wedge factor values are also checked for all photon beams using the same reference conditions.

2.3. Monthly QA

Monthly checks involve more extensive checks of the radiation, safety and mechanical parameters. The QA procedure includes checks on the mechanical system, the image-forming and image detection system, couch accuracy, accuracy of gantry movement, accuracy of lasers, accuracy of cross wires and collimators, light / radiation field coincidence, door interlocks, anti-collision devices, optical distance indicator accuracy and emergency stop buttons. Table 1. describes an overview of the monthly QC checks performed in accordance with these local QA procedures.

2.4. Annual QA

Annual QA checks are a scaled down version of the commissioning checks. It is a major QC exercise and is intended to validate the treatment unit for another twelve months. It involves the use of water phantoms to measure beam profiles and depth dose curves. In addition to yearly recommended QA checks, Planned maintenance checks [8] are done to keep the system at correct operating conditions and to make sure that the equipment continues to operate for as long as possible without unplanned corrective maintenance. Although clinical users do not do PM, it is ensured that those PM programs are fully up to date (6 and 12 monthly PM, 2, 3, 5 and 7 yearly PM performed by Elekta engineers and technicians).

2.5. Individual Patient QA

Patient QA is an essential part of general QA implementation. Plan printouts should be approved, dated and saved by the responsible radiation oncologist, with dose prescription clearly written on the plan. This should also be reviewed and signed by a medical physicist prior to first treatment. To reduce errors on the first setup, an independent verification of the treatment parameters are made after the first fraction. These include MU check, field size check, gantry and collimator check, In vivo dosimetry check, port film check etc. All machine parameters used for patient setup should be correct. In addition, independent calculation of the dose at isocenter and Dmax values on the central axis for every field is made. When deviations are above the threshold, certain actions are taken. Such as, changing the isocenteric depth to radiological equivalent depth in inhomogeneous medium, repositioning of the

Dmax point correctly and correct estimate of the percentages of the field size covered with multi leaf collimators (MLCs).

Table 1. QA tasks with tolerances and average deviations from analysis.

FREQUENCY	PROCEDURE	TOLERANCE	AVERAGE DEVIATION
Daily	**Dosimetry**		
	Photon and electron output constancy	±3%	-0.8% and -1.38%
	Mechanical		
	Localizing lasers	2mm/±1mm	0.2mm
	Collimator rotation with central axis	2mm	0.1mm
	Optical distance indicator(ODI)	2mm	0.1mm
	Safety		
	Door interlock	Functional	Functional
	Audiovisual monitors	Functional	Functional
Weekly	**Dosimetry**		
	Photon and electron output constancy*	±3%	0.53% and 1.50%
	Wedge factor constancy	3%	0.3%
	Mechanical		
	Gantry angle isocenter	2mm	0.1mm
	Collimator isocenter	2mm	0.1mm
	Beam/field size alignment	2mm	0.2mm
Monthly	**Dosimetry**		
	Photon and electron output constancy*	±3%	0.45% and 1.52%
	Wedge factor constancy	3%	0.3%
	Photon and electron beams flatness constancy	3%	1.0% and 0.5%
	Photon and electron beams symmetry	3%	1.5% and 1.3%
	Calibration of daily Output dosimeter	3%	0.8% and 1.6%
	Mechanical		
	Gantry/collimator angle readouts	1 degree	0.2 degree
	Optical distance indicator	2 mm	0.1mm
	Field size indicators	2 mm	0.1mm
	Treatment couch position indicators	2mm/1 degree	0.1mm and 0 degree
	Localizing lasers	2 mm	0.15mm
	Light and treatment field coincidence	2 mm	0.7mm
	Light field congruence with Collimator	2 mm	0.3mm
	Imaging system QA	Optimum quality	Optimum quality
	Safety		
	Emergency off switches	Functional	Functional
	Door Interlocks	Functional	Functional
	Anti-collision devices	Functional	Functional
	Planned maintenance procedures**	Up to date	Up to date
Yearly	**Dosimetry**		
	Photon flatness and symmetry	2%	1.0% and 1.3%
	Electron flatness and symmetry	2%	0.4% and 1.1%
	Photon/electron output calibration	2%	0.8%
	Mechanical		
	Gantry and treatment table isocenter	2mm	0.5mm
	Planned maintenance procedures**	Up to date	Up to date
	Safety		
	Follow manufacturer's test procedures**	Functional	Functional

* With different gantry angles ** Elekta planned maintenance checklist

3. Results

These results represent the dosimetric, mechanical and safety tests done on the Elekta linear accelerator (photons and electrons) at SGMC as well as patient specific QAs. Table 1. shows the average deviations from the tolerance values adopted for the QA procedures performed over the 20-month period. As seen from the tables, the daily constancy check shows reproducibility and a stable delivery of dosimetric quantity of better than ±3%. For daily QA, two action levels were established based on the tolerances. Action level 1 was set for deviations of ±3%, where treatment continues but the senior physicist is notified immediately for inspection. For deviations more than ±3%, action level 2 was set; where treatment was to be stopped immediately and the problem investigated by the responsible senior physicist. The results of the daily check were always within tolerances before the Linac was passed for clinical use.

Table 2. Dosimetric deviations of QA task.

	`		Wedge factor		Flatness		Symmetry		Dosimeter	
Dosimetry	**Avg (%)**	**Max (%)**	**Avg (%)**	**Max (%)**	**Avg (%)**	**Max (%)**	**Avg (%)**	**Max (%)**	**Avg (%)**	**Max (%)**
Monthly										
Photon	0.45	1.30	1.32	1.8	1.04	1.35	1.52	2.31	0.79	1.88
Electron	1.52	2.00	N/A		0.50	0.78	1.34	1.92	1.63	2.60
Weekly										
Photon	0.53	1.90	0.35	1.85	N/A		N/A		N/A	
Electron	1.50	2.60	N/A							
Daily										
Photon	-0.80	-3.00	N/A		N/A		N/A		N/A	
Electron	-1.38	-4.00								

4. Discussion

For daily QA tests, those parameters which could seriously affect patient positioning and therefore the registration of the radiation field and target volume (lasers, ODI); patient dose (output constancy) and safety (door interlock and audiovisual contact) were included. From table 1, all these parameters checked were within the acceptable limits and in good working condition. The radiation dosimetry checks are performed with calibrated diodes; hence higher deviations expected. Weekly dosimetric QA checks were very similar to the daily but performed with a sensitive ionization chamber to confirm the daily radiation outputs. As seen in the figure 1, the variations of weekly photon dosimetric QA values over time were within 2% of the ionisation chamber-measured reference value, although there appears to be a slight positive trend over time for both energies. With over 98 percent of our patients been treated with photons, it is a clear evidence of the fact that there is consistency of dose delivered to patients over the

evaluation period. Monthly photon dosimetric QA values also had similar variations and were within 2% of reference value. As expected all weekly mechanical checks were all within tolerance.

All the tests included in the tables are important for ensuring that the equipment is suitable for high quality and safe radiation treatments. As seen in the table 2, the variations of the weekly dosimetric values over time were within 2.6% of the ionisation chamber-measured reference values, with a slightly upward trend for electrons. Variation of gantry angles did not have any dosimetric effect on the outcome of these QA checks. A wedge factor constancy of 0.35% average was recorded for the photon energies. Collimator and gantry isocenters which could affect dosimetric outcome both had an average deviation of 0.1mm from reference values. For monthly we include more refined testing of parameters which will either have a smaller impact on the patient (e.g., treatment couch indicators) or have lower likelihood of changing over a month (e.g., light and radiation field or beam flatness). Monthly measurements over the period show an average percentage difference of 0.45% for the photons and 1.52% for the electron beam as compared to the values obtained at commissioning. The maximum difference between dosimetric QA values and reference values is about 1.3% for photon beam and 2% for the electron beam. Values which do not follow the normal or expected trends were repeated under the same conditions. The differences as expected were mainly due to procedural errors or wrong input data. For the yearly QA checks, one of the dosimetric parameters that required monitoring was the beam output, specified as the absorbed dose on the central axis under reference conditions. This was to validate the absolute dose calibrations of megavoltage photon and electron beams using the International Atomic Energy Agency (IAEA) technical report series (TRS 398) [9]. The deviation was below tolerance value with an average deviation of 0.8% from commissioning values. Using IBA OmniPro-ImRT software and the MatriXX, the flatness and symmetry of the various beams and energies were obtained using the IEC protocols. From Fig.2; (a) is the profile for 6MV photon, (b) for 15MV photon, (c) for 6MeV electron, (d) for 10MeV electron and (d) for 15MeV electron beam. All the monthly and yearly beam flatness and symmetry were within set tolerance values. The less sensitive diodes are used for quick daily checks and were operating within prescribed tolerances of 3%. Calibration of daily Output dosimeter was done by comparing dosimeter values with the equivalent reading obtained from the calibrated ionisation Chamber. Average deviations of 0.8% and 1.6% were obtained for photon and electron dosimeter calibration factors respectively. If the deviation is less than ±3%, no action is taken, if the deviation is higher than ±3%, the dose meter is recalibrated.

A custom built LAS VAGAS QA Phantom was used in analyzing the image forming and detection system. Digital images were obtained and the number of holes at every row and columns apart were evaluated using the iView software tool. Monthly analysis of all the images produced an optimum image quality. The images were also observed for distortions.

QA for individual Plans had deviations below the defined tolerance value with an average dose deviation at isocentre of 2.4% and 1.7% for Doses at maximum depths (Dmax) using an independent MU program. Other independent verification of the treatment parameters made before and after the first fraction were within allowable

limits. The experimental techniques for performing these QA tests are not discussed in this work, as they are described in a number of publications cited.

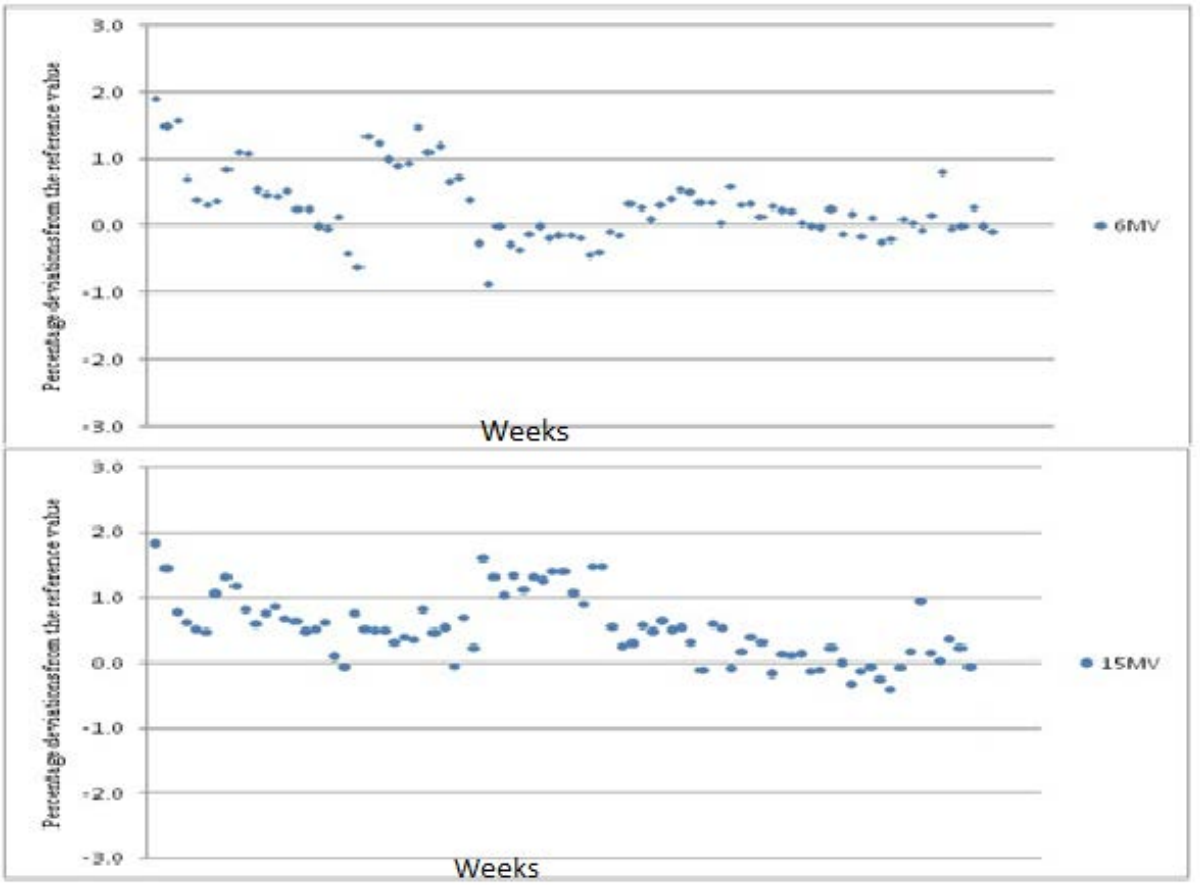

Fig. 1. Variation of weekly photon dosimetry over the 20-month period for 6 MV and 15MV

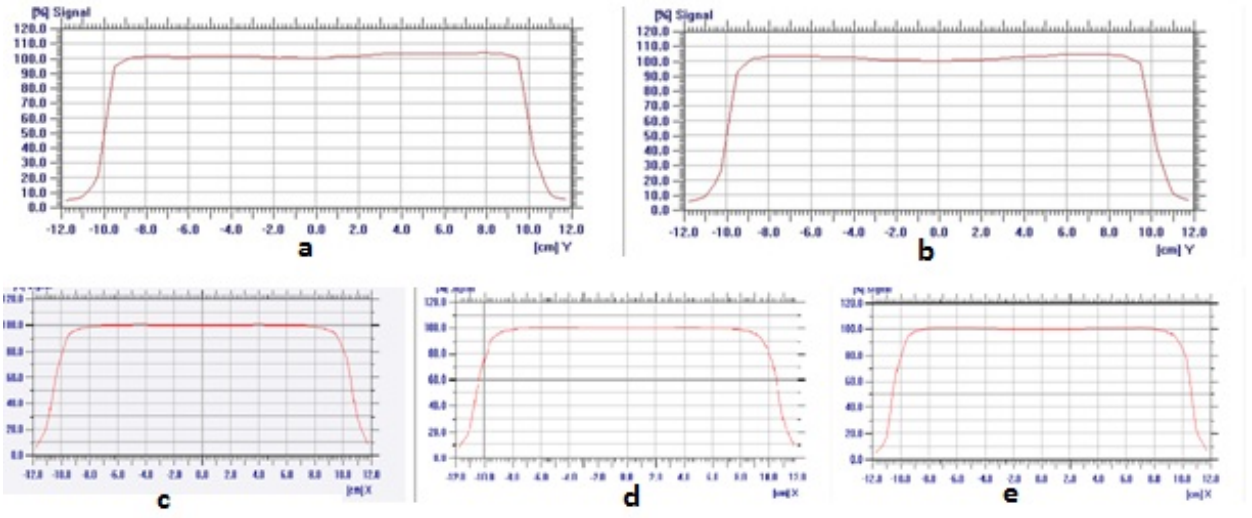

Fig.2. Sample beam profiles for analyzing symmetry and flatness.

5. Conclusion

The QA procedures were structured to meet the clinical requirement for accuracy; necessary to achieve optimum treatment. This quality requires a multidisciplinary team effort, as it is concerned with the reduction of errors and uncertainties in every aspect of the radiotherapy process. From this stems the need to perform stringent and regular QC checks, in terms of dose accuracy, for the Linac to deliver specific doses to the tumor. For the preparation of this manual, it was decided to rely as much as possible on well-known published national and international guidelines [1, 2, 3, 4] as well as the Elekta recommended checks [8]. The structure of this document was intended to be as general as possible (logistically and human resources wise), in order to be easily adapted to the different structures of Ghanaian and West African radiotherapy departments. At the same time, this document aimed to introduce a reasonable level of uniformity for Linac QA methods throughout Ghana and West Africa. It should be noted that, these procedures, however, be considered as recommendations and not as mandatory Checks. The daily, weekly and monthly tests discussed here should be adequate to detect any potential problems in the operation of the Linac and delivering of accurate prescribed doses. Reproducibility of these procedures over the 20-month period for the Linac, as well as the accuracy and repeatability of the treatment plans generation and dose delivery were excellent.

After analyzing and evaluating the results of all the QA checks done over the 20 month period, it became prudent to introduce additional QA checks to the existing document. SGMC radiotherapy policies and procedure manuals were also to be reviewed yearly and updated as QA procedures change. An external quality audit team (probably, ESTRO equal or the local radiation protection institute (RPI)) is to investigate our local QA protocols and advice accordingly. Adherence to the QA outlined is to be followed unless there is demonstrable reason to modify them. Parameters which show large deviations from their baseline values should be given special attention and checked more frequently. Alternatively, if careful and extended monitoring demonstrates that a parameter does not change, or hardly changes at all, then the frequency for monitoring this parameter could be reduced. Although it is difficult to recommend how long a parameter should be monitored before decreasing the test frequency.

It was recommended that the magnitude of any deviations from the reference value were to be recorded for each test, rather than simply using a tick/OK to confirm that the test has been carried out and the results lie within the allowed tolerance limits. This enables trends to be seen and actions taken before the tolerances are exceeded. Finally, the execution of the checks requires the appropriate allocation of time and of human resources, which directly affects the daily workload of the treatment machines. Therefore, the quality assurance procedures should be considered as an integral part of the machine workload and the required time should be allocated within the normal working hours.

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