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Author: Tommy Knöös
Joakim Medin

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A dosimetric intercomparison between the radiation therapy clinics in Sweden

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SSM perspective

Background

The accurate delivery of absorbed dose to cancer patients undergoing radiotherapy is critical to the success of this treatment modality. To achieve an accurate delivery of absorbed dose it is essential to use calibrated reference instruments for dosimetry, quality assured procedures for determining the absorbed dose according to international dosimetry protocols and to have qualified personnel. Independent external dosimetry audits are also a valuable tool for quality assurance of the delivery of absorbed dose. It is not mandatory in Sweden to perform external audits for dosimetry on a regular basis. It is, however, mandatory to perform an external, independent, monitoring of the dose in the radiation field before new equipment is taken into clinical operation. The last external dosimetry audit, which included all radiotherapy departments in Sweden, was performed in 1982. Due to the long period of time since the last national dosimetry audit was performed, the Swedish Radiation Safety Authority (Strålsäkerhetsmyndigheten, SSM) decided to support the current study.

Objectives

The objective of the study was to analyze the dosimetric quality at the radiotherapy departments in Sweden delivering high energy radiotherapy with linear accelerators. An external dosimetry audit was performed which included a) input CT data to treatment planning, b) beam calibration under reference conditions, c) delivery of a standard set of beams, and d) delivery of a 5-field prostate type treatment plan.

Results

In general the study showed a good agreement between the results from the audit team and the local team. The examination of the reference dosimetry showed an excellent agreement between the absorbed dose determined by the audit team and the local team. The spread of the results among the Swedish radiotherapy departments was much lower as compared to similar studies conducted in other countries. SSM believes that this is mainly due to the fact that the latest international dosimetry protocols are followed at each department. SSM (former the Swedish Radiation Protection Institute, SSI) promoted the implementation of the latest IAEA dosimetry protocol by arranging a course in 2002. The study also found errors in the CT transfer to density at two departments and at one department misalignment of the laser-positioning system was found.

Need for further research

The present study does not include a dosimetry audit of more complex treatment techniques, such as intensity modulated arc therapy, which are currently being introduced at several departments in Sweden. SSM believes that external dosimetry audits are also important for such more advanced techniques. There is also a need for the development of a system for performing regular external dosimetry audits in Sweden.

Project information

Contact persons at SSM: Linda Persson and Peter Björk
Reference: SSM 2009/2554

Strål
säkerhets
myndigheten
Swedish Radiation Safety Authority

Authors: Tommy Knöös and Joakim Medin
Skåne University Hospital and Lund University, Lund, Sweden

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This report concerns a study which has been conducted for the Swedish Radiation Safety Authority, SSM. The conclusions and viewpoints presented in the report are those of the author/authors and do not necessarily coincide with those of the SSM.

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A dosimetric intercomparison between the radiation therapy clinics in Sweden

Tommy Knöös and Joakim Medin

Skåne University Hospital Lund and Lund University
Radiation Physics
S-221 85 Lund
Sweden

Abstract

A dosimetry audit have been performed during 2009-2011 in Sweden, initiated by the medical physics group in Lund and supported by the national authority for radiation safety. There are 18 departments delivering high energy radiation therapy with about 65 linear accelerators, but for this study only one or in a few exceptions two units have been included per department. The audit cover a) input CT data to treatment planning, b) beam calibration under reference conditions, c) delivery of a standard set of beams and d) delivery of a 5-field prostate type treatment plan. The measurements are performed with a commercial phantom covering most types of tissues present in the body for the CT input data. Dose determination in reference geometry was accomplished with an ionisation chamber/electrometer combination according to the international code of practice TRS-398. For the two final parts, an electronic semi-three dimension diode detector system were used to sample 1069 dose points which then were used for evaluation against the dose distribution from the local treatment planning system. The visited institutes are equipped with one of two different brands of treatment planning systems and most of the users have not or do not have the possibility to change the transfer of CT-number/Hounsfield units to electron density to be used in the dose calculations. The transfer function at each department have, however, been checked thus any changes from the default settings have been recorded. The results for the reference dosimetry shows an excellent agreement between the absorbed dose determined by the local user and the audit team (1.002 ± 0.004, k=1), especially the small spread should be noted.

Contents

Introduction

An external audit of radiotherapy is a method of identifying systematic errors both in data and in procedures implemented at the local department. Audits can cover several steps in the radiotherapy process e.g. beam calibration, target definition, dose calculations, and the delivery of treatment. Several national audits have been performed in many European countries during the last decades e.g. United Kingdom [20], Poland [9], and Germany [5]. There have also been international audits, for example, one initiated by ESTRO (European Society for Radiotherapy and Oncology) covering nine European countries with 66 participating centres [2]. That study included beam calibration under reference conditions but several other studies have also included dose measurements in other geometries. The EORTC (European Organisation for Research and treatment of Cancer) organised an audit for departments participating in clinical trials which was reported in three papers where the last included dosimetric data from more anatomical shaped geometries [10]. The ESTRO-EQUAL study during 1998 included beam calibration but also percent depth doses, output factors as well as wedge transmission factors [4]. One of the most comprehensive external audit programmes is available from the Radiological Physics Center (RPC) at the M.D. Anderson Cancer Center formed by the American Association of Physicist in Medicine (AAPM) and funded by e.g. the National Cancer Institute in the USA[1].

The previous national inter-institutional dosimetry audit in Sweden was reported in 1982 [11] though some departments have been participating in the international audits mentioned above. Thus, a project was initiated by the medical physics group at Lund University Hospital (presently Skåne University Hospital) and the Swedish Radiation Safety Authority during 2008-2009 to perform a dosimetry audit of the radiotherapy centres in Sweden. External dosimetry audits can in principle be performed in two ways, either as mailed service or by site visits. In this project it was decided to do site visits in order to reduce the uncertainty and it started late 2009 and ended at the beginning of 2011 and included all 18 sites in Sweden which provide external radiation therapy with high energy photon beams (figure 1). Preliminary results from the present audit were presented at the international symposium on standards, applications and quality assurance in medical radiation dosimetry organized by the IAEA [13].

1: More information available at http://rpc.mdanderson.org

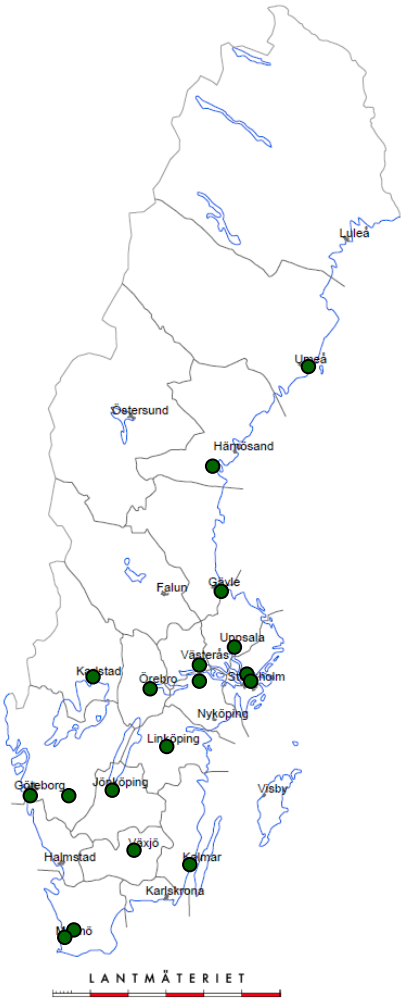

Figure 1. Map of the 18 sites visited during the dosimetry audit.

Materials and Methods

The present audit covers three steps in the radiotherapy chain. The first was the input data to the treatment planning system (TPS) consisting of computerised tomography (CT) attenuation distributions i.e. CT-numbers or Hounsfield Units (HU), which are the base for dose calculation. The second sub-process was the absorbed dose calibration of the linear accelerator under reference conditions [6] and the last step was the validation of the local commissioning of algorithm input data, see definition by IAEA (International Atomic Energy Agency) [7], facilitated through measurements of absorbed dose distributions in discrete points for simple beam configurations evaluated against calculations with the local TPS.

CT-data

A plastic phantom with cylinders of different electron densities reproducing various tissue properties was scanned using a common planning protocol in the local CT-scanner and transferred to the local treatment planning system (TPS) in order to analyze the conversion of Hounsfield units to densities (or electron densities).

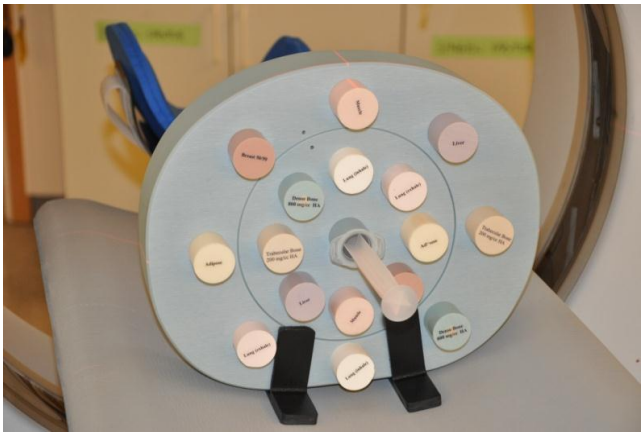

Figure 2. The density phantom positioned on the CT-scanner couch ready to be scanned.

A commercial phantom, shown in figure 2, was used (Electron Density Phantom 062, by Computerized Imaging Reference Systems, CIRS, Inc, VA, USA) which includes insert covering the most common tissues, see Table 1.

Tissue/Material	Physical Density (g/cm^3)	Electron density ($e^-/cm^3 \times 10^{23}$)	Electron density relative to water
H_2O Syringe	1.00	3.340	1.000
Lung (Inhale)	0.20	0.634	0.190
Lung (Exhale)	0.50	1.632	0.489
Breast (50/50)	0.99	3.261	0.976
Dense Bone $800mg/cm^3$	1.53	4.862	1.456
Trabecular Bone $200mg/cm^3$	1.16	3.730	1.117
Liver	1.07	3.516	1.052
Muscle	1.06	3.483	1.043
Adipose	0.96	3.170	0.949

Table 1. Tissue substitutes in the CT phantom for evaluation of Hounsfield unit to density conversion.

Absorbed dose under reference conditions

Absorbed dose measurements under reference conditions according to the IAEA TRS-398 [6] were performed in a water phantom with PMMA walls. This phantom was designed and built at the audit team's workshop with dimensions 25x25x35 cm^3 with two tubes for ionisation chambers of Farmer 0.6 cm^3 type. One chamber was used for the measured charge and the second for monitoring the stability of the beam during the set of measurements. The ratio of the two readings was also used when determining the two correction factors for polarity effect and recombination, which was done for all beam qualities investigated (39 different beams). All measurements in the audit phantom were performed with the gantry at 0° defined according to IEC 61217 [8] i.e. the beam was vertical and enters the water without passing any PMMA.

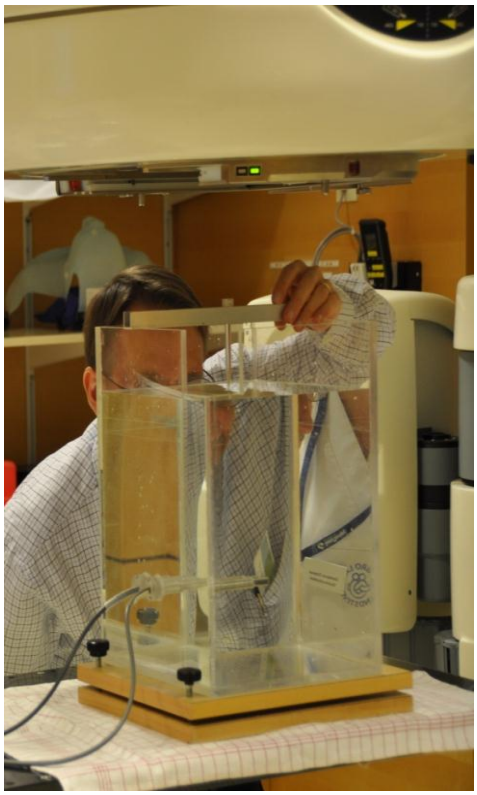

Figure 3. The audit team's water phantom positioned for irradiation. Fixed distance rods were used to determine the distance from the upper edge of the phantom down to the water level while the ionization chambers have a fixed position thus assuring the correct depth of measurement. The phantom was placed on a dual-plate with three adjustment screws to facilitate the levelling.

The chamber used for the determination of absorbed dose under reference conditions (NE2571, serial number 3591) was calibrated at the Swedish Secondary Dosimetry Laboratory, traceable to the BIPM (Bureau International des Poids et Mesures) in Paris, both before and after this audit and was found to be stable within 0.05%. In addition, the ionchamber/electrometer equipment was constancy checked at ^{60}Co before and after each travel to the participating centres during the audit period. The electrometer used for all reference dosimetry measurements was a PTW Webline (serial number 103), calibrated at the Swedish national standards laboratory for electrical units, traceable to primary standards at the same laboratory.

In addition, before and after each travel with the chamber, it was constancy controlled in ^{60}Co, together with the electrometer, at the Skåne University hospital in Lund. Temperature and pressure were measured with the audit teams' own equipment. The calibration of the thermometer (Testo model 925) is traceable to the Swedish national primary standard for temperature via an Hg-thermometer (ArnoAmarell Precision, serial number 9711), and the barometer (Druck model DPI 142, serial number 1986507) was calibrated at the Swedish Secondary Standards Laboratory for pressure, traceable to the primary standards at BNM-LNE (Bureau National Metrologie - Laboratoire National d'Essais) in Paris and NPL (National Physical Laboratory) in London.

All measurements by the audit team were performed using the reference geometry of the visited hospital, i.e. either with a setup where the centre of the ionisation chamber was positioned at isocenter (SAD setup) or with the isocenter at the surface of the water and the chamber at the reference depth (SSD setup). Both the local physicists (using their own equipment) and the audit team determined the absorbed dose in the reference geometry at the visit as close as possible in time to each other. A few visited sites had determined the absorbed dose before the arrival of the audit team, but always on the same day. At a vast majority of the visited sites the two independent determinations of reference dose was made within 2h of each other.

The audit team have determined the $TPR_{20,10}$ for all studied beams and the corrections factors for the polarity effect k_{pol}, ion recombination k_s and the ambient correction factor $k_{t,p}$ considering the difference in conditions compared to the calibration at the SSDL[2]. All equipment used by the audit team has been calibrated biennially by the standard laboratories in Sweden. This includes barometer, thermometer, electrometer and ionisation chambers.

2: Secondary Standard Dosimetry Laboratory, SSDL.

Validation of treatment data

A crucial step regarding accuracy in the radiotherapy process is the commissioning of data to the TPS and maintaining them throughout the life time of the linear accelerator. Several methods are used and different data sets or algorithm input data are required for the various TPS on the market. Independent on the methodologies and contents, the accuracy of the delivered treatment to the patient is dependent on the agreement of the predicted/calculated dose from the TPS and the output of the treatment unit. The treatment planning systems used at the participating sites are listed in table 2.

Type	Version	# sites
Varian Eclipse	7.5.51	1
	8.2.24	1
	8.6.15	5
	8.6.17	1
	8.9.09	3
Nucletron Oncentra MasterPlan	OTP V3.2.0.303	3
	OTP V3.3.1.3	4

Table 2. The treatment-planning systems used at the participating clinics.

Field size (cm^2)	Gantry angle	Collimator rotation	Open or wedged beam
10x10	0°, 90°, 270°	0°	Open
10x10	0°	0°, 90°, 270°	Open
5x5, 5x20, 20x5	0°	0°	Open
10x20	0°	0°	Wedge 20°, Wedge 60°

Table 3. List of the standard fields evaluated with the diode array detector system.

In this audit a set of standard fields (table 3) calculated in the local TPS were compared with measurements using a diode-array detector (Delta^4, ScandiDos AB, Uppsala, Sweden). The fields calculated with the local dose-planning system were exported to the detector system software, the fields were delivered and the resulting dose distribution was sampled. This was done for each photon beam quality at the linear accelerators included in the audit. The Delta^4-detector has recently been introduced to the community and a few reports have

been published showing its accuracy to verify highly complex treatment modalities [1], [14], [19].

From these measurements, the correct use of output factors for three different field sizes could be checked, related to a standard 10x10 cm^2 field. These fields were also used to control any erroneous position of leaves or jaws. In addition the correct description of the implemented wedge was controlled by comparing the measured wedge profile with the calculated. The irradiations performed with collimator and gantry rotation were used for diagnostic purposes, i.e. to determine if a field-size error was caused by mlc/jaws misalignment or a set-up error due to laser or field cross-hair positioning errors.

As a final control during this audit, a 3D conformal plan for prostate was delivered to the Delta^4-detector. A ball-shaped structure was first added to an artificial CT-set obtained from ScandiDos, representing the Delta^4-detector. These CT-images had been mathematically generated at ScandiDos having constant HU/density in the whole PMMA phantom. The participating departments were then instructed to make a dose plan with their own TPS based on the parameters presented in table 4. Beam weighting varied slightly between the different sites, but in general the field weights in table 4 were applied. All irradiations were done with 6 MV and 2 Gy was planned to the centre of the composite dose distribution. In this context it should be noted that the chosen plan parameters were not intended to produce a clinically realistic 3D prostate irradiation, but for example to use an energy available at all participating sites. The slightly varying field weights has no significance since the results between sites were not compared but only the possible difference between the planned and delivered absorbed dose at each specific site.

Field #	Gantry angle	Collimator rotation	Open or wedged beam	Field weight
1	270°	95°	Wedge 60°	100%
2	330°	0°	Open	25%
3	0°	0°	Open	15%
4	30°	0°	Open	25%
5	40°	0°	Wedge 60°	100%

Table 4. Beam parameters used for the 3D conformal prostate plan.

Before the Delta^4-detector was used for the measurements described above, its diode-arrays were calibrated relative to the ionization chamber used for the reference dosimetry. This was done for every beam quality at all visited sites and the detector response was thereby

related to the absorbed dose in a standard field size (by ScandiDos referred to as ”absolute calibration“). In addition, the user should make a so called ”relative calibration“ of the diode arrays, providing correction factors for the varying diode responses. This has to be done for only one beam quality and was performed at the audit team's own department before every travel with the detector system. When arriving at a department having a beam energy that had not been used before, a "directional calibration" of the diode arrays had to be done in addition to the “absolute calibration”. The applied calibration procedure follows the recommendations provided by ScandiDos when using this detector system in various beam qualities.

Results and Discussion

CT-data

The results obtained with the commercial phantom shown in figure 2 are presented in figure 4a and 4b for the inner and outer ring, respectively. The results are also presented in table 5a and 5b. One CT-data file per site was analysed with the freeware program ImageJ[3], choosing a centrally located slice in the data set. A circular area with a size covering the smallest material plug (dense bone) in the CT-phantom was used, which gave the average HU-value for each material in figures 4a and 4b and tables 4a and 4b.

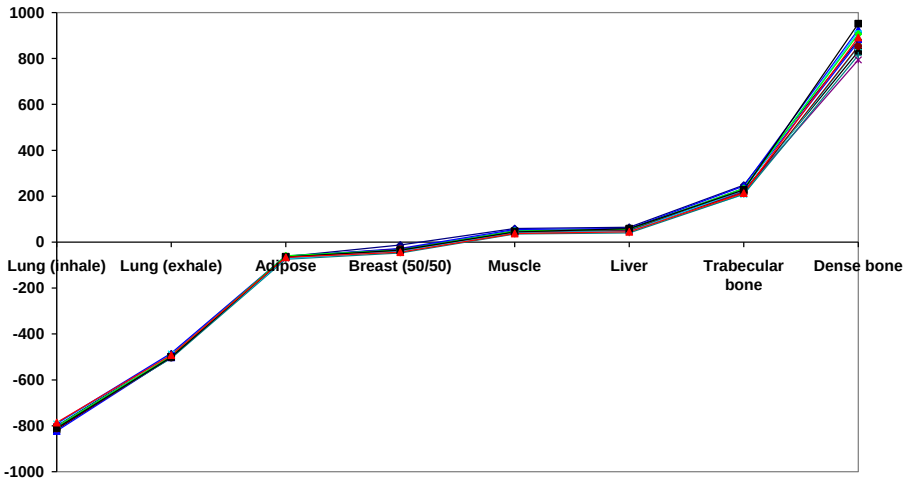

Figure 4a. Hounsfield units obtained with the CIRS-phantom at 12 of the visited sites for the different materials positioned in the inner ring of the phantom.

3: See http://imagej.nih.gov/ij

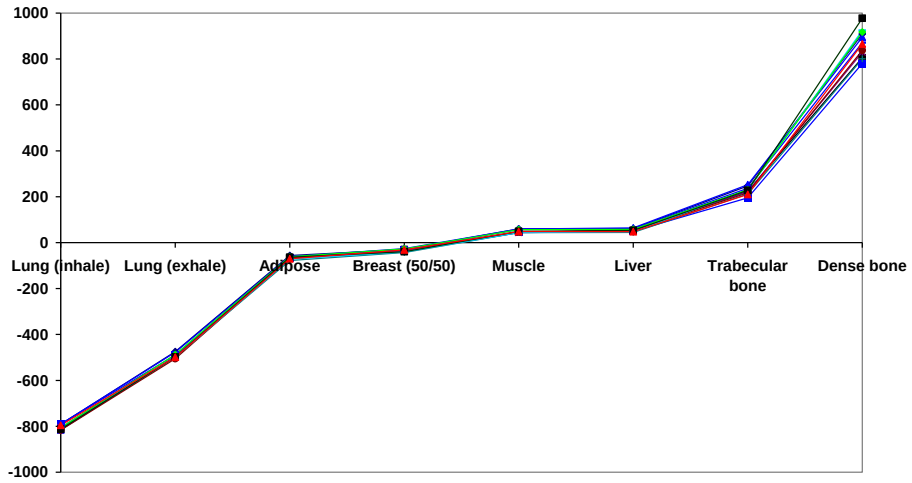

Figure 4b. Hounsfield units obtained with the CIRS-phantom at 12 of the visited sites for the different materials positioned in the outer ring of the phantom.

Site	Lung (inhale)	Lung (exhale)	Adipose	Breast (50/50)	Muscle	Liver	Trabecular Bone	Dense bone	Water
A	-806	-496	-71	-41	43	46	227	917	-4
B	-801	-486	-62	-13	59	65	249	881	9
C	-810	-501	-65	-35	44	59	228	951	-11
F	-786	-492	-66	-43	38	45	214	892	-22
G	-822	-502	-64	-27	56	59	245	927	0
I	-789	-484	-60	-31	50	55	234	872	5
K	-804	-497	-59	-34	49	56	234	907	-1
L	-807	-506	-75	-47	35	41	209	814	-17
M	-803	-498	-69	-40	42	50	222	794	-7
N	-792	-487	-68	-39	42	46	208	851	-17
P	-812	-503	-65	-30	41	53	216	853	-3
Q	-816	-500	-64	-35	48	53	222	831	-3
Mean	-804	-496	-66	-35	46	52	226	874	-6
1 SD	11	7	4	9	7	7	13	48	9
Max	-786	-484	-59	-13	59	65	249	951	9
Min	-822	-506	-75	-47	35	41	208	794	-22

Table 5a. Hounsfield units obtained with the CIRS-phantom at 12 of the visited sites for the materials in table 1 positioned in the *inner ring* of the phantom.

Site	Lung (inhale)	Lung (exhale)	Adipose	Breast (50/50)	Muscle	Liver	Trabecular Bone	Dense bone
A	-805	-498	-72	-40	43	48	230	924
B	-791	-475	-56	-30	60	61	247	909
C	-812	-498	-64	-39	49	53	228	978
F	-795	-498	-70	-31	48	47	210	866
G	-815	-497	-62	-26	59	64	253	895
I	-790	-478	-61	-30	58	60	236	871
K	-807	-488	-62	-28	56	58	231	917
L	-807	-499	-78	-43	44	44	212	801
M	-805	-497	-69	-37	44	49	222	830
N	-791	-490	-65	-31	46	50	195	780
P	-817	-505	-68	-31	45	52	217	838
Q	-814	-498	-67	-30	46	52	223	806
Mean	-804	-493	-66	-33	50	53	225	868
1 SD	10	9	6	5	7	6	16	59
Max	-790	-475	-56	-26	60	64	253	978
Min	-817	-505	-78	-43	43	44	195	780

Table 5b. Hounsfield units obtained with the CIRS-phantom at 12 of the visited sites for the materials in table 1 positioned in the *outer ring* of the phantom.

Among the visited sites, only two brands of TPS's (Varian Eclipse and Nucletron OnCentra Masterplan) were represented and most users were using the default settings for importing and transferring the CT data to density maps for the dose calculation, i.e. both dose-planning systems were in fact using the same data [12]. The two systems are available at the auditors department, thus, we have collected all scanned CT data in DICOM format and the HU for each included density was evaluated directly from the images. During the present audit it was found that the default transfer function had been changed at two departments (A and B). At the first site (A), this change resulted in erroneous results for the high density regions. After this audit, the local physics group at that site has gone back to the default settings. At the second site (B) the default function had been slightly "refined" by adding a few extra data points.

Since all dose planning systems used at the visited clinics base their transfer from HU to density or electron density on the same set of data [11], the HU-values in table 5a and b have been transferred to electron densities using that data set and compared with the nominal data for the various materials in the audit CIRS-phantom. Linear interpolation has been used between the data points presented in [11],yielding the results in table 6a and 6b. It should be noted that this comparison presumes that the default transfer function has not been altered, which would affect the results for site A.

Site	Lung (inhale)	Lung (exhale)	Adipose	Breast (50/50)	Muscle	Liver	Trabecular Bone	Dense bone	Water
A	-0.7%	0.5%	-4.3%	-3.9%	-1.6%	-2.2%	4.9%	1.2%	-2.2%
B	2.1%	2.2%	-3.4%	-1.1%	0.2%	-0.2%	5.3%	0.1%	-0.2%
C	-5.3%	-0.3%	-3.6%	-3.3%	-1.4%	-0.8%	4.9%	2.1%	-0.8%
F	9.6%	1.3%	-3.8%	-4.2%	-2.1%	-2.3%	4.6%	0.4%	-2.3%
G	-18.6%	-0.5%	-3.5%	-2.6%	-0.3%	-0.8%	5.2%	1.4%	-0.8%
I	8.1%	2.7%	-3.1%	-3.0%	-0.8%	-1.2%	5.0%	-0.1%	-1.2%
K	1.3%	0.4%	-3.1%	-3.2%	-1.0%	-1.2%	5.0%	0.9%	-1.2%
L	-1.7%	-1.1%	-4.6%	-4.6%	-2.4%	-2.7%	4.5%	-1.7%	-2.7%
M	1.0%	0.2%	-4.1%	-3.8%	-1.6%	-1.8%	4.8%	-2.3%	-1.8%
N	6.7%	2.0%	-3.9%	-3.8%	-1.7%	-2.2%	4.5%	-0.7%	-2.2%
P	-7.7%	-0.7%	-3.7%	-2.8%	-1.7%	-1.5%	4.6%	-0.6%	-1.5%
Q	-11.9%	-0.1%	-3.5%	-3.4%	-1.0%	-1.4%	4.8%	-1.3%	-1.4%
Mean	-1.4%	0.6%	-3.7%	-3.3%	-1.3%	-1.5%	4.8%	0.0%	-1.5%
Max	-18.6%	-1.1%	-4.6%	-4.6%	-2.4%	-2.7%	4.5%	-2.3%	-2.7%
Min	9.6%	2.7%	-3.1%	-1.1%	0.2%	-0.2%	5.3%	2.1%	-0.2%

Table 6a. Percentage deviation between electron densities obtained from the results in table 5a, using data in [11], and the nominal electron densities for the CIRS phantom. Results are for the plugs in the *inner ring* of the phantom.

Site	Lung (inhale)	Lung (exhale)	Adipose	Breast (50/50)	Muscle	Liver	Trabecular Bone	Dense bone
A	-0.5%	0.2%	-4.4%	-3.8%	-1.5%	-2.0%	4.9%	1.4%
B	6.8%	4.2%	-2.7%	-2.9%	0.2%	-0.6%	5.3%	1.0%
C	-7.7%	0.2%	-3.5%	-3.8%	-0.9%	-1.4%	4.9%	2.9%
F	4.9%	0.2%	-4.2%	-2.9%	-1.0%	-2.0%	4.5%	-0.3%
G	-11.1%	0.5%	-3.3%	-2.5%	0.2%	-0.3%	5.4%	0.5%
I	7.3%	3.7%	-3.2%	-2.9%	0.0%	-0.7%	5.1%	-0.1%
K	-1.7%	1.9%	-3.3%	-2.6%	-0.2%	-0.9%	4.9%	1.2%
L	-1.8%	0.1%	-4.9%	-4.1%	-1.5%	-2.4%	4.5%	-2.1%
M	0.1%	0.4%	-4.0%	-3.5%	-1.5%	-1.9%	4.8%	-1.3%
N	7.3%	1.6%	-3.7%	-3.0%	-1.2%	-1.8%	4.2%	-2.7%
P	-12.5%	-1.0%	-3.9%	-3.0%	-1.3%	-1.5%	4.7%	-1.1%
Q	-9.8%	0.2%	-3.8%	-2.9%	-1.3%	-1.5%	4.8%	-2.0%
Mean	-1.6%	1.0%	-3.7%	-3.2%	-0.8%	-1.4%	4.8%	-0.2%
Max	-12.5%	-1.0%	-4.9%	-4.1%	-1.5%	-2.4%	4.2%	-2.7%
Min	7.3%	4.2%	-2.7%	-2.5%	0.2%	-0.3%	5.4%	2.9%

Table 6b. Percentage deviation between electron densities obtained from the results in table 5b, using data in [11], and the nominal electron densities for the CIRS phantom. Results are for the plugs in the *outer ring* of the phantom.

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Absorbed dose under reference conditions

All visited sites were following the IAEA TRS-398 Code of Practice with a 50/50% choice of SAD or SSD setup except for two sites which instead performed all beam calibrations with an SSD of 95 cm and with the chamber centre positioned at 5 cm depth for all energies. The TRS-398 gives the possibility to perform measurements at 5 cm for energies where the $TPR_{20,10}$ is less than 0.7, however, these two sites violate the Code of Practise for the higher photon energies. In spite of this, the audit team applied the locally used geometry also for the high energy photon beams in order to perform a more direct comparison of the absorbed doses, compared to introducing additional sources of uncertainties via the transfer of absorbed doses between two different depths in the water phantom.

In total, 39 beam qualities were included in the dosimetry audit, obtained with 20 different accelerators at the 18 sites visited. The results are presented in figure 5 and 6 where a small positive offset can be noted, indicating that the audit team more often arrived at a lower value of the absorbed dose than the local physicist group. However, the average value of all results, expressed as the ratio of the "audit dose" and the "local dose", is 1.002±0.004 (k=1). When comparing this outcome with previous results from audits conducted in other countries, the small spread among the various Swedish radiation therapy departments is particularly noteworthy, *cf.* table 7. The range of the $TPR_{20,10}$ for the beams included in this audit is shown in figure 7 and 8, based on the audit team's determination.

In order to evaluate the obtained deviation between the "audit" dose and the "local" dose one has to consider the various contributing uncertainties. In TRS-398, the combined standard uncertainty of the absorbed dose to water under reference conditions for a high-energy photon beam is estimated to be 1.5% (k=1). This amount is largely reduced in the present inter-comparison since it involves a ratio of two absorbed-dose determinations. The largest contribution to the combined standard uncertainty in TRS-398 originates from the relatively large uncertainty in the tabulated k_Q value (1%), which has been reduced to 0.05% in the present work. This estimate is based on the fact that when calculating the ratio of the two values of absorbed dose, the only uncertainty in k_Q that remains is from the determination of the beam-quality and its influence on the interpolated k_Q value. The other major contributors to the TRS-398 estimate (1.5%) originates from the dosimeter reading relative to beam monitor (0.6%) and the combined uncertainty from the standards laboratory (0.6%). The former was reduced to 0.1% since both sets of measurements were obtained close in time of each other and comparing the observed

deviations in the additional ionisation chamber used as beam monitor during the measurements. The latter contribution was reduced to 0.15% based on the fact that the uncertainty in the calibration of the SSM secondary standard at the BIPM cancels.

With an estimated combined standard uncertainty of 0.6% (k=1) for the absorbed-dose ratio, none of the observed deviations in the present national audit can be considered to be significant.

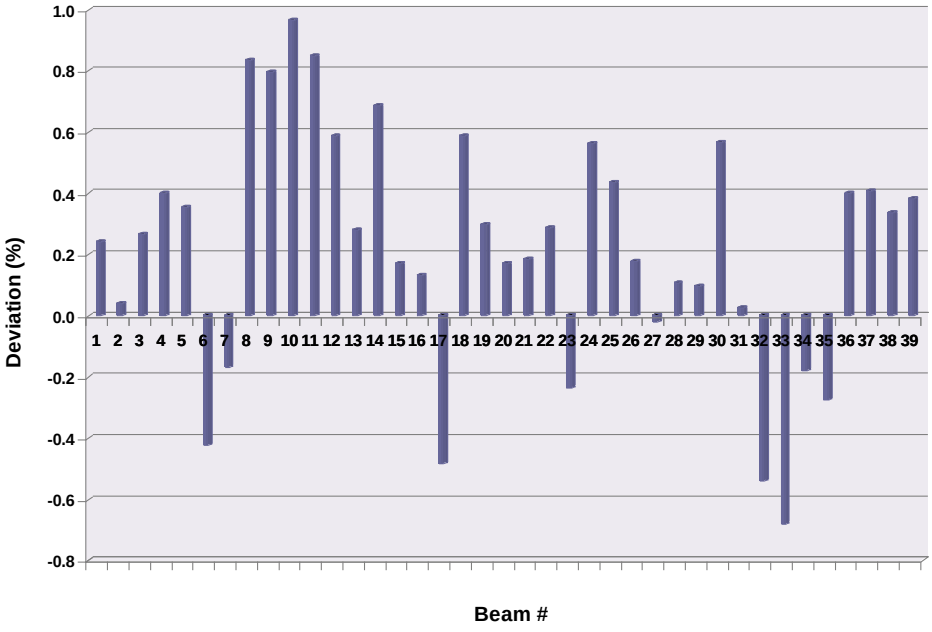

Figure 5. Percentage deviation between the absorbed dose determined by the local physicists and the audit team at reference conditions from 39 beams.

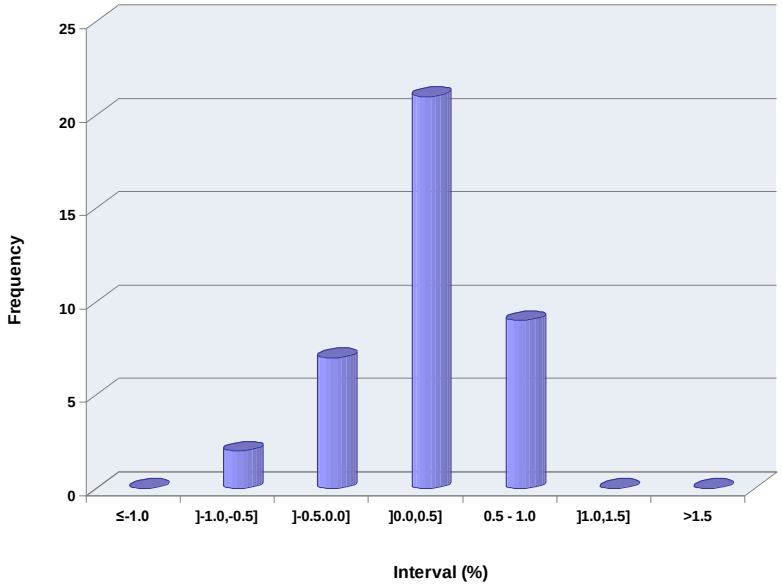

Figure 6. Frequency distribution of deviations (in percent) between the absorbed dose determined by the local physicists to the absorbed dose determined by the audit team at reference conditions from 39 beams.

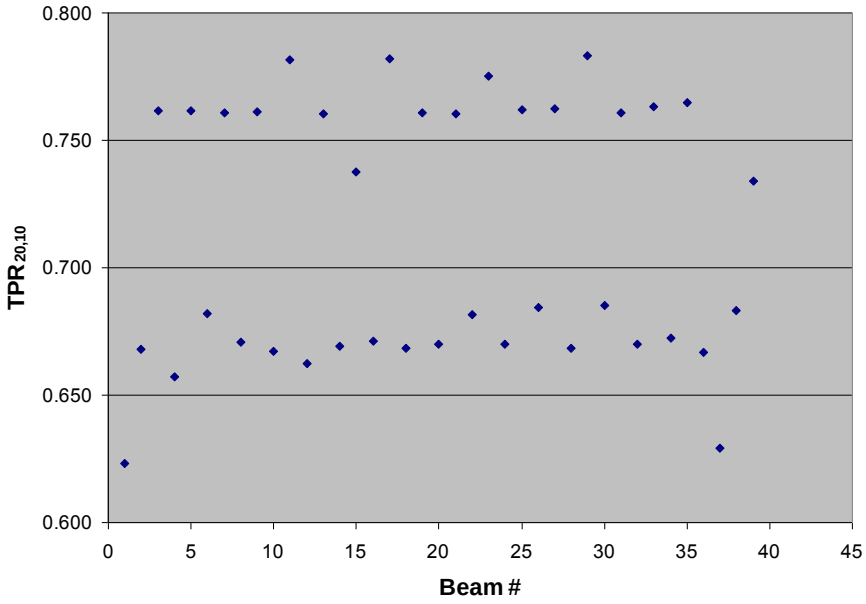

Figure 7. $TPR_{20,10}$ for the beams included in the present audit.

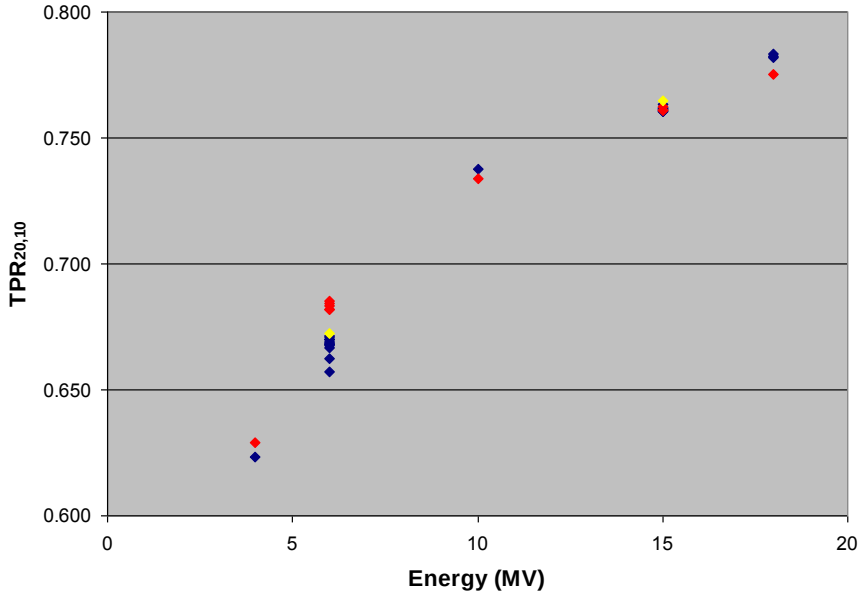

Figure 8. $TPR_{20,10}$ for the beams obtained with the Varian- (26 beams, blue), Elekta- (11 beams, red) and Siemens-linacs (2 beams, yellow) included in the audit.

Reference	Region	# beams	Average	SD (%)
Johansson *et al*., 1982	Scandinavia	50	1.017	2.3
Johansson *et al*., 1986	Europe	16	1.024	3.3
Wittkämper *et al*., 1987	The Netherlands	40	1.008	2.0
Hanson *et al*., 1991	International (mainly US)	740 [b]	1.008	1.9
Thwaites *et al*., 1992	UK	100	1.003	1.5
Dutreix *et al*., 1994	Europe	125 119 [a]	0.970 0.985 [a]	9.5 2.5 [a]
Izewska *et al*., 1995	Poland	22	1.004	3.8
Nisbet *et al*., 1998	Ireland	13	1.002	1.2
Ferreira *et al*., 2001	Germany	114 [b]	0.996	2.1
Kroutilikova *et al*., 2003	Czech Republic	362 [b]	1.000	2.8
De Angelis *et al*., 2005	Italy	16	1.009	1.6

Table 7. Results from some previous national and international dosimetry audits, obtained from chapter 7, table 7.2 in [16]. For full details about the references included see [16]. [a] Excluding deviations >12%. [b] Including results from ^{60}Co.

Validation of treatment data

When analyzing the output for various field-sizes, the summed output from the diodes within a 3x3 cm^2 central-positioned area at both detector planes was evaluated. The percentage deviation between the measured absorbed dose and the calculated absorbed dose was compared for each field-size and normalized to the result obtained for the standard 10x10 cm^2 field. The delivered field-size compared with the field-size from the dose planning system was checked by only considering diodes along the edges of the field, realized by analyzing DTA (distance-to-agreement) for deviations larger than 2 mm and for regions where the dose changes more than 3%/mm. The investigation of various field-sizes revealed a few unexplained deviations, in which cases the results will be followed up with the appropriate departments. These deviations relate both to the output factor for the largest field-size (20x20 cm^2), where six sites had deviations of larger than 2% (ranging from 2.5-3.5%) when normalised as described above. At two sites, the smallest field-size (5x5 cm^2) led to deviations between 3-4%. No faulty leaf or jaw positioning could be found during the present audit.

The wedged fields where analysed by looking at the summed output from the diodes within the 6x6 cm^2 central-positioned area at both detector planes. The difference between the measured absorbed dose and the calculated dose was considered acceptable if it was below 2%, and all centres except four fulfilled this criterion. These centres failed with the 60° wedge, and three of these centres were included amongst the ones failing the field-size test. The reasons for these deviations are difficult to find based on one single measurement, and an extended investigation was outside the scope of the present project.

A gamma analysis [15] has been performed for the five-field prostate treatment, both for the composite treatment and for each individual field using a criterion of 3% absorbed dose difference and 3 mm distance-to-agreement. These criteria were regarded as reasonable considering the combined uncertainty in set-up and laser alignment. In this evaluation, all detectors receiving an absorbed dose larger or equal than 20% of the absorbed dose at the centre of the field are included. In figure 9 a screen dump from the bi-planar diode detector system is shown for one of the irradiations. A summary of both the composite agreement and, when available, beam individual beam gamma analysis agreement is shown in table 8 below.

All departments except two had results where the fraction of measurements having gamma values less than unity (conforming fraction) was well above 90 %. At one of these two sites (site K), the passing-rate increased from 87.5% to 97.7% for the composite plan when taking a misalignment of the laser-positioning system into

account by moving the measured dose distribution 4 mm. This misalignment was found when comparing with the standard 10x10 cm^2 field. The largest deviation was found at site A where they have introduced their own conversion function for HU to electron density in their TPS (*c.f.* CT-data above). It has to be noticed that this error only resulted in erroneous dose values for density above 1.1 relative to water and the worst case is actually for PMMA phantoms as used in this audit.

Points failing are most commonly positioned at the edges of the dose distributions which could be due to several factors. Among these we have the positioning system at the local clinic i.e. the isocenter mark-up system – the positioning lasers which directly influence the placement of the detector system (for example site K). Another major contributor could be the modelling of the penumbra in the TPS and especially since all these beams are shaped by multi leaf collimators (MLC). Both the MLC modelling and the calibration of them on the accelerator may contribute to these disagreements.

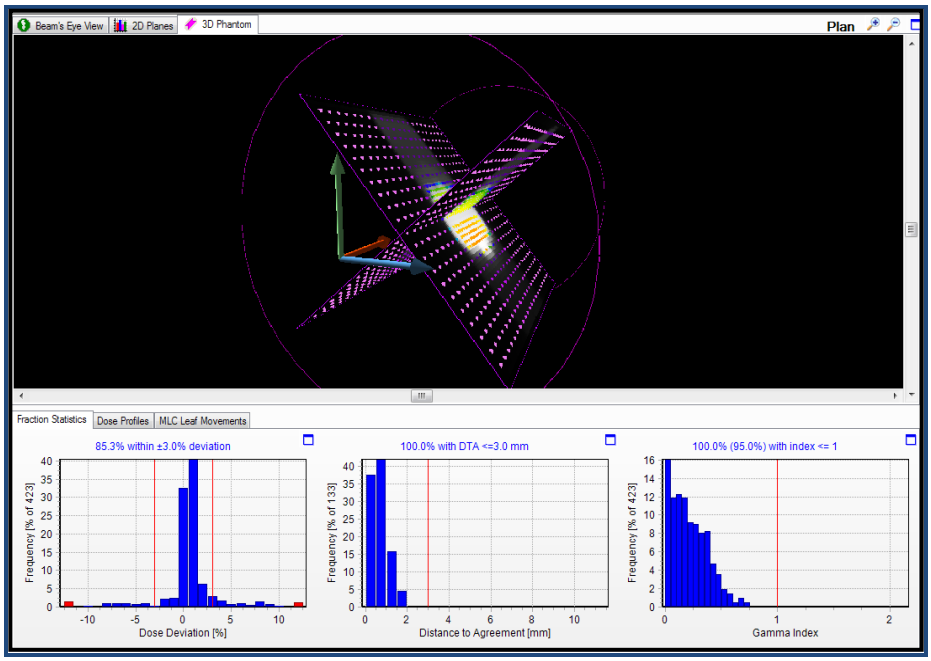

Figure 9. Example of an evaluation of a measurement with the diode array detector. In the upper panel, the two diode planes are shown with the dose distribution. In the lower, we have from left to right; dose deviation, distance-to-agreement, and gamma distribution with dose and distance criteria of 3% and 3 mm, respectively.

In a survey performed for one vendor's system at 139 clinics it was found that 76 % and 83 % of them was using 3 % and 3 mm, respectively, as criteria for the gamma analysis during planar IMRT verifications. It was also reported that a pass rate of 90-95% was applied in most cases [18]. The AAPM task group 119 suggests the same criteria for field-by field evaluation combined with a pass rate of

90% [3]. Thus, for a semi 3D geometry as used in this audit, it may be motivated to use similar criteria and pass rate for clinical acceptance.

Site	field #1	field #2	field #3	field #4	field #5	Composite
A	-	-	-	-	-	29.9
B	100.0	75.8	100.0	100.0	100.0	100.0
C	-	-	-	-	-	97.4
D	99.0	99.0	98.8	97.7	98.1	99.3
E	100.0	96.5	100.0	100.0	100.0	100.0
F	96.5	94.2	99.4	96.1	98.4	98.2
G	100.0	99.8	100.0	100.0	100.0	100.0
H	100.0	95.2	100.0	99.5	100.0	100.0
I	100.0	99.2	100.0	98.2	100.0	100.0
J	93.7	70.6	98.8	93.4	95.4	93.8
K	79.9	88.3	90.4	90.4	94.8	87.5
L	95.4	96.2	97.5	93.8	94.8	97.9
M	96.5	96.0	99.1	95.2	100.0	99.3
N	99.4	88.2	100.0	86.3	95.8	97.9
O	99.3	77.1	97.1	79.6	94.1	98.7
P	100.0	100.0	99.7	100.0	100.0	100.0
Q	99.4	98.3	99.7	98.2	100.0	99.3
R	100.0	100.0	100.0	100.0	100.0	100.0
					On average	98.1

Table 8. Fraction of measurements with gamma less than unity with an evaluation criteria of 3% and 3 mm for the 5-field prostate like treatment. The average value excludes site A. For two of the sites, only data for the composite field is available.

Conclusions

The audit process at each hospital has been performed either during two afternoons/evenings or during a full day where the machine have been available to both the local and the audit teams, a total of 7-8 hours have been spent on each unit. A very short time have been spent on the CT scanners, less than 15 min, and this has easily been accomplished at all departments.

From this audit the following conclusions can be made:

- For the CT transfer to density, the transfer was performed according to the international standard built in by the vendor. Two cases were found, however, where users have edited the transfer function resulting in erroneous transfer in one of the departments for

densities above about 1.2 relative to water. The transfer function was subsequently corrected afterwards.

- Reference dosimetry is performed according to the TRS-398 at all departments except for two. In these two cases the selected geometry does not conform to the TRS-398 recommendations. In practice, this has no significant consequence for the patient dosimetry with the specific type of linacs used at these two departments. From a fundamental point-of-view and in order to guarantee a high accuracy in clinical dosimetry it must be considered very important to comply with international standards for dosimetry.

- The agreement between the local and the audit team regarding reference dosimetry is very good with a small average deviation (1.002) and especially a rather small spread (1 SD = 0.004).

- The irradiation with the standard fields (see table 3) revealed a few deviations larger than 2% for the smallest and largest field sizes (two and six, respectively) and four centres failed on the 2%-criterion for the 60º wedged field. No faulty leaf or jaw positioning could be found during this investigation, and the reasons for the observed deviations are difficult to find based on one single measurement. An extended investigation was outside the scope of the present project.

- The five field prostate plans have been delivered with high agreement between measurements and treatment planning calculations. The conforming fraction for the gamma analysis with a criteria of 3%/3mm were on average 98.1 % [87.5-100] except for one institute where the error in the HU conversion resulted in a very low conformity.

This study has shown the value of external audits where systematic errors can be detected. It has also shown that the dosimetry procedures at the visited department are performed at high quality.

For the future, we conclude that regular audit programs should be established to assure the high quality present today at Swedish radiotherapy departments especially within the area of dosimetry. This should be a future task to be assured by the national regulators.

Such programmes should include reference dosimetry as well as more complicated situations and also include other steps in a modern radiotherapy process. The audit should include not only methods for accurate dose levels but also assure the safe delivery in space (position) and time (gating and tracking procedures). This should include audit of e.g. image guided RT, positioning devices, dose verifications systems, and image devices (CT, MR, PET/CT).

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Strålsäkerhetsmyndigheten
Swedish Radiation Safety Authority

SE-171 16 Stockholm
Solna strandväg 96

Tel: +46 8 799 40 00
Fax: +46 8 799 40 10

E-mail: registrator@ssm.se
Web: stralsakerhetsmyndigheten.se