Thermoluminescent dosimeters (TLD) quality assurance network in the Czech Republic

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Abstract

Introduction: The Czech thermoluminescent dosimeters (TLD) quality assurance network was established in 1997. Its aim is to pursue a regular independent quality audit in Czech radiotherapy centres and to support state supervision.

Materials and methods: The audit is realised via mailed TL dosimetry. The TLD system consists of encapsulated LiF:Mg,Ti powder (type MT-N) read with Harshaw manual reader model 4000. Basic mode of the TLD audit covers measurements under reference conditions, specifically beam calibration checks for all clinically used photon and electron beams. Advanced mode consists of measurements under both reference and non-reference conditions using a solid multipurpose phantom (‘Leuven phantom’) for photon beams. The radiotherapy centres are instructed to deliver to the TLD on central beam axis absorbed dose of 2 Gy calculated with their treatment planning system for a particular treatment set-up. The TLD measured doses are compared with the calculated ones. Deviations of ±3% are considered acceptable for both basic and advanced mode of the audit.

Results: There are 34 radiotherapy centres in the Czech Republic. They undergo the basic mode of the TLD audit regularly every 2 years. If a centre shows a deviation outside the acceptance level, it is audited more often. Presently, most of the checked beams comply with the acceptance level. The advanced TLD audit has been implemented as a pilot study for the present. The results were mostly within the acceptance limit for the measurements on-axis, whereas for off-axis points they fell beyond the limit more frequently, especially for set-ups with inhomogeneities, oblique incidence and wedges.

Conclusions: The results prove the importance of the national TLD quality assurance network. It has contributed to the improvement of clinical dosimetry in the Czech Republic. In addition, it helps the regulatory authority to monitor effectively and regularly radiotherapy centres.

Keywords: Quality assurance; Thermoluminescent dosimeters audit; Dosimetry intercomparison; Mailed dosimetry; Thermoluminescence dosimetry

1. Introduction

It is generally accepted that ±5% uncertainty in dose delivery to the target volume can be considered as a safe limit causing no severe radiotherapy treatment consequences [7,15]. Due to the complexity of procedures involved in radiotherapy, from beam dosimetry, patient data acquisition, treatment planning, to the irradiation of the patient, the development and application of relevant quality assurance (QA) programme seem to be a key factor in reducing overall uncertainty associated with subsequent steps of the radiotherapy process.

In the Czech Republic, quality assurance programme is aimed particularly at radiotherapy treatment machines. According to the Czech laws radiotherapy treatment machines are classified as ‘significant sources of ionising radiation’. Consequently, their use is licensed on condition that an adequate local quality assurance programme is implemented. In general, the programme is based on sets of acceptance tests, status tests and constancy tests that have to be performed regularly. The particular methods are specified in the set of recommendations issued by State Office for Nuclear Safety (SONS). All tests include also on-site measurements to control both dosimetric and non-dosimetric parameters of a radiotherapy machine.

Since a quality audit performed by an independent institution is one of important tools of a comprehensive quality assurance programme, each radiotherapy centre has to undergo an independent quality audit regularly also. Two types of audits are employed: on-site audit and thermoluminescent dosimeters (TLD) postal audit. The on-site audit is

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performed by an external auditing group (EAG) of experienced medical physicists who are licensed for this work. TLD audit is realised via mailed dosimetry within the frame of Czech TLD QA network.

As a radiotherapy treatment is planned mostly using computerised treatment planning systems (TPS), it is obvious that precision of the calculated dose distribution is vital for the success of the treatment. Despite this fact, and in contrast to radiotherapy treatment machines, there is neither any law nor any guideline focused on QA of treatment planning systems in the Czech Republic. Considering this fact, it will be useful to create a list of basic requirements, with which the treatment planning systems must conform, and these basic standards must be taken into account when choosing a new treatment planning system. For this purpose, a project ‘Quality Assurance in Radiotherapy – Treatment Planning Systems’ is being developed at present. The Ministry of Health and State Office for Nuclear Safety support the project. Within the project, a method of advanced TLD audit is applied as a tool for independent quality audit in radiotherapy focused on dosimetric checks of several simple treatment techniques generated by means of TPS. It is realised within the Czech TLD QA network.

This paper summarises experiences from 5 years’ operation of the TLD QA network. It presents results achieved within the operation of the basic and advanced TLD audits and analyses the situation in the Czech Republic.

2. Infrastructure of Czech radiotherapy centres

In the Czech Republic (population approximately 10 millions), the number of new cancer patients, who undergo radiotherapy, either curative or palliative, reaches about 20 thousands per year (approximately 40% of all new cancer patients).

There are 67 high energy radiotherapy treatment machines operating at present time in the Czech Republic, delivering external radiation therapy to cancer patients: 28 60Co units, 19 linear accelerators, two betatrons and 18 137Cs units. The 137Cs units are used for palliative cancer treatment or non-cancer disease treatment and there are attempts to remove them from the clinical practice. The named 67 machines are distributed among 34 radiotherapy institutions. Small radiotherapy centres equipped with one or two radionuclide units predominate. There are only ten centres, which are equipped adequately (linear accelerator, computed tomography (CT), simulator, advanced computer planning system, complete dosimetric equipment, skilled personnel) to provide modern high quality radiotherapy.

There are eight different types of radiotherapy treatment planning systems presently used in the Czech Republic. They are distributed among 29 radiotherapy centres, the remaining five centres have no treatment planning system, but these institutions are equipped only with a 137Cs unit and do not perform any radical cancer treatment. Particular types of treatment planning systems currently used in the Czech Republic are summarised in Table 1.

Most of the Czech radiotherapy centres use the domestic TPS PlanW, which ordinarily is referred to the small regional radiotherapy centres. In these centres, average annual number of patients, who undergo radiotherapy, ranges from 200 to 500. Seven large centres have systems like CadPlan or CMS-Focus. Their average annual number of radiotherapy patients usually exceeds 1000 per centre.

In order to gather some information on current treatment planning practice, a detailed questionnaire had been prepared and distributed to all Czech radiotherapy centres. Participation rate achieved of 76%, and so a lot of information on patient data acquisition, dosimetry data acquisition, features, capabilities, advantages and disadvantages of those specific types of treatment planning systems were collected. In addition, a local practice in quality assurance related to TPS was inquired. There were a few significant findings:

- acquisition of CT patient data is realised via on-line transfer only for the CadPlan, CMS-Focus and Theraplan systems, the other systems use indirect methods for the CT transfer (data medium, digitiser, film scanner, etc.);
- on-line connection between TPS and simulator was referred only for CadPlans and Theraplan;
- on-line connection between TPS and verification system was referred only for CadPlans;
- use of identical table tops in the sequence CT – simulator – treatment machine was referred only for one of CadPlan and three of PlanW;
- dosimetric data are loaded into the treatment plan-

Table 1
TPS presently used in the Czech Republic

<table>
<thead>
<tr>
<th>Treatment planning system</th>
<th>Producer</th>
<th>Last software upgrade</th>
<th>Number in use</th>
</tr>
</thead>
<tbody>
<tr>
<td>CadPlan</td>
<td>Varian Medical Systems, Dosetec</td>
<td>1998–2001</td>
<td>5</td>
</tr>
<tr>
<td>PlanW</td>
<td>Mach., Czech Republic</td>
<td>1997–2001</td>
<td>16</td>
</tr>
<tr>
<td>CMS-Focus</td>
<td>Computerized Medical Systems</td>
<td>1999</td>
<td>2</td>
</tr>
<tr>
<td>Theraplan</td>
<td>MDS Nordion – Theratronics</td>
<td>1993</td>
<td>1</td>
</tr>
<tr>
<td>Target 2</td>
<td>GE Medical Systems</td>
<td>1999</td>
<td>1</td>
</tr>
<tr>
<td>Prowess 3000</td>
<td>Prowess Systems, SSGI</td>
<td>1994</td>
<td>2</td>
</tr>
<tr>
<td>Multidata</td>
<td>Multidata Systems Int. Corp.</td>
<td>1997</td>
<td>1</td>
</tr>
<tr>
<td>Plato</td>
<td>Nuclotron</td>
<td>Unspecified</td>
<td>1</td>
</tr>
</tbody>
</table>
ning system electronically (on-line, data medium, RSS-232) for CadPlan, CMS-Focus, Target 2 and several PlanW systems, other systems use a manual way for dosimetric data transfer;

- most of the radiotherapy centres use their own measured dosimetric data, but two of them use dosimetric data from another radiotherapy centre (PlanW), four of them partly use data supplied by the producer (Theraplan, one of CadPlan, one of PlanW);

- only 45% of the radiotherapy centres have introduced some QA for their treatment planning systems, in addition the reported local QA procedures differ very much in extent from each other.

3. TLD QA network

The Czech national TLD network was established in 1997. The TLD network measuring centre is situated at the National Radiation Protection Institute (NRPI) in Prague. The establishment of the network was supported through the Czech participation in the pan-European Radiation Oncology Programme for Assurance of Treatment Quality (EROPAQ), pan-European Radiotherapy Quality Assurance (EURAQA) [10,13] and IAEA projects. On this basis, pertinent methods [12] were adapted and conformed to Czech local conditions. From the very beginning, the aim was not only to achieve improvement of clinical dosimetry, but also to report the results to SONS, who is responsible for radiation safety and patient protection programme in the Czech Republic.

A basic TLD audit, which has been pursued since 1997, involves dose measurements under reference conditions, specifically beam calibration checks for all clinically used photon and electron beams. At the end of 1998, two multipurpose phantoms were obtained via participation in EROPAQ/EURAQA and IAEA projects [6,10,13]. After a short testing period, when the methodology was checked, the advanced TLD audit was brought into practise in the course of 1999. It involves measurements both under reference and non-reference conditions for external photon beams.

4. Materials and methods

4.1. TLD system

Lithium fluoride powder LiF:Mg,Ti (type MT-N produced by TLD Niewiadomski) has been chosen as the TLD material for the Czech TLD quality assurance network. Its effective atomic number ($Z_{\text{eff}} = 8.14$) makes it close to tissue equivalence ($Z_{\text{eff,tissue}} = 7.42$). The grain size of the material is between 80 and 200 μm. The choice of the powder material makes measurements more demanding but it is justified by the great precision that must be reached for quality control measurements. The powder is annealed before it is used for dose measurements in order to optimise its characteristics. The annealing is performed at 400°C for 1 h followed by fast cooling and subsequent annealing at 100°C for 2 h. The powder is reused only three times and therefore no other special powder treatment (for example sieving) is applied.

The dosimeters are closed in opaque cylindrical polyethylene waterproof capsules identical to those used by the IAEA [8]. Each capsule contains about 160 mg of powder that provides nine to ten identical portions (15.8 mg ± 1.3%) to be read after the powder is dispensed. The dispensing is made into metallic containers that are small enough to be put onto the reader’s planchette. TLD manual Harshaw reader model 4000 is used for readouts. The applied heating cycle consists of a preheating at 130°C for 8 s, followed by a linear increase of the temperature of 10°C s⁻¹ to a maximum of 250°C where the signal is integrated within 20 s. During all readouts glow curves are recorded in order to eliminate possible errors due to the temperature shift of the reader.

The TL responses of the identical samples previously irradiated to 2 Gy exhibit a Gaussian distribution with coefficient of variation for the individual TL reading, $\nu = 1.9\%$. Coefficient of variation of the mean for a single TL capsule, $\nu_C$, does not exceed 0.7% then ($\nu_C = \nu / \sqrt{n} - 1$ where $n$ is number of readings per capsule).

In order to determine a calibration factor of the TLD system, $K_{\text{cal}}$, the reference dosimeters are irradiated to 2 Gy in a $^{60}$Co beam at the Department of Oncology of the First Faculty of Medicine, Charles University in Prague. The irradiation is performed under reference conditions in a water phantom using the IAEA standard holder. The TL dosimeter is positioned at the depth of 5 cm, at the distance of 100 cm from the $^{60}$Co source within the irradiation field of $10 \times 10$ cm². The dose is determined by measurement with reference kit of NRPI, a PTW 30002 ionisation chamber connected to a PTW Unidos 10002 electrometer. The dose is determined according to the IAEA protocol [5]. The equipment is calibrated annually in the Czech secondary standards dosimetry laboratory SSDL. In order to determine the absorbed dose to water from the TLD reading, several correction factors have to be applied. These are related to beam quality, non-linearity in dose response, fading and the IAEA holder attenuation at the quality [10]. They are determined separately for each batch of powder. The energy correction factor, $K_{\text{en}}$, is applied when the quality of the investigated beam differs from the $^{60}$Co reference beam. The correction, $K_{\text{ref}}$, related to the photon beam attenuation due to the IAEA holder is of significance for the check of depth dose data at depths of 10 and 20 cm. The dose response linearity correction factor, $K_{\text{lin}}$, becomes significant when the measured dose differs from the reference value of 2 Gy. Fading correction factor, $K_{\text{fad}}$, is of significance only if the system calibration is performed at a different time than the irradiation of the dosimeters to be checked. The correction factors were determined in accordance with methodologies published previously [2,9]. If $R$ is the TLD reading normalised
to the mass of aliquot of the powder, then the absorbed dose to water is:

\[ D = RK_{\text{cal}}K_{\text{lin}}K_{\text{fad}}K_{\text{en}}K_{\text{hol}} \]

The total uncertainty of the determination of the \( D \) using the TLD system is estimated by the square root of the quadratic sum of individual uncertainties of the TLD calibration with ionisation chamber and of the correction factors (linearity, fading, energy dependence, IAEA holder). The total uncertainty at 1 SD is 1.5% for \(^{60}\text{Co}\) beams, 1.9% for X-ray beams and 2.3% for electron beams.

The accuracy of the TLD measurements has been confirmed several times by means of different intercomparisons – particularly annual intercomparisons provided by IAEA and intercomparisons performed formerly within the EROPAQ and EURAQA projects.

4.2. Basic TLD audit

The basic TLD audit is provided for both photon and electron beams. Photon and electron IAEA holders [3,8,11] that are necessary for the purpose were distributed to all Czech radiotherapy centres. When the audit is required, the audited radiotherapy centre is provided with a group of TLD capsules, an instruction sheet describing the method of TLDs’ irradiation, a data sheet to enter specifications regarding the radiotherapy treatment machine, other dosimetry equipment and details about TLDs’ irradiation. The audit covers beam calibration check and the irradiation must be performed under reference conditions. In case of photon beams, the TLD capsule is fixed by the holder to be positioned at the depth of 5 or 10 cm in an appropriate water phantom for field size of 10 \( \times \) 10 cm\(^2\) with common source-skin-distance (SSD) or source-axis-distance (SAD) set-up. Dose of 2 Gy is required to be delivered. For the beam quality check, TLD capsules are positioned at depths of 10 and 20 cm. Field size of 10 \( \times \) 10 cm\(^2\) and SSD = 100 cm have to be set up. Dose of 2 Gy is required for the upper capsule. In case of electron beams, the TLD capsule is fixed by the particular holder to be irradiated at the depth of \( d_{\text{max}} \) to dose of 2 Gy. Field size of 10 \( \times \) 10 cm\(^2\) and common SSD are used concurrently.

The radiotherapy centres are requested to irradiate the TLDs during a predetermined time window. At the same time the TLD system is calibrated. This helps to keep the fading under control.

4.3. Advanced TLD audit

The advanced TLD audit consists of measurements under both reference and non-reference conditions using a solid multi-purpose phantom for photon beams developed in Leuven in the frame of the EC-network project [1,2] (so called ‘Leuven phantom’) that enables to check a substantial part of the treatment planning process inclusive of the dose delivery to the target volume. Some procedures that patients usually undergo during the radiotherapy process can be modelled in this way, including the sequence from CT data acquisition to treatment planning and then finally the phantom irradiation in accordance with the calculated plan.

The phantom consists of a few coherent parts. Its central part is adjusted to insert TLD or a verification film (Fig. 1). The phantom is made from polystyrene (\( \rho = 1.05 \text{ g/cm}^3 \)), though one of the parts contains an air inhomogeneity and a wood inhomogeneity (\( \rho = 0.34 \text{ g/cm}^3 \)) simulating lung tissue. The location M of the TLD capsule is on central beam axis. The locations R and L are referred to off axis measurements, right or left 2.5 cm off central beam axis. A more detailed description of the phantom is given in [1].

The audit procedure consists of a sequence of several steps that simulate the process of treatment preparation and realisation. The phantom is assembled to a requested set-up first. Thereafter a CT scan image through the central transversal plane of the phantom is taken using the markers on the phantom surface. The CT slice is transferred by a usual way to the treatment planning computer. Then a few required irradiation set-ups are simulated. The planned dose for the point containing TLD on the central beam axis is 2 Gy. The irradiation of the phantom with TLDs or film in place has to be made according to the calculated plan. Consequently, it is possible to compare the planned dose for the TLD points with the doses measured by TLD afterwards. Films are irradiated only in the reference set-up, and the applied dose should be within the range from 0.3 to 0.4 Gy. Evaluation of the film is used to check parameters of dose profiles of the beam.

The irradiation of the phantom including TLDs usually is performed for 7 simple irradiation set-ups currently used in clinical radiotherapy, basically with common SSD (SAD), open fields and vertical incidence set-up, at depths of 5 or 10 cm depending on beam quality. More details are given in Table 2. During all the tests the TLDs are exactly in defined positions inside the phantom. Generally they are not placed in regions with very steep dose gradients, so the TL dosimeter dimension does not influence the accuracy of dose measurement significantly.

The films are read using a laser densitometer (Lumiscan 50) that was calibrated for the given region of doses and energies. The films are used to evaluate following para-
meters: field size, homogeneity, symmetry and penumbra. These parameters can, in some cases, immediately indicate anomalies in radiation field of radionuclide treatment machines.

All participants of the study were provided with an instruction sheet describing the irradiation procedures with the phantom and dosimeters. They were given a data sheet to enter parameters of the therapy machine, TPS, and details concerning TLD and film irradiation.

4.4. Reporting of deviations

The TLD measured doses are compared with the doses stated (calculated) by the radiotherapy centre. For all dose measurements, the deviation between TLD measured and stated dose is reported:

\[ \Delta_D = \left( \frac{D_{\text{TLD}}}{D_s} - 1 \right) \cdot 100\% \]

An acceptance level of \( \pm 3\% \) has been set for this deviation. Deviations from \( \pm 3\% \) up to \( \pm 6\% \) are considered minor, deviations exceeding \( \pm 6\% \) are regarded major and deviations exceeding \( \pm 10\% \) are emergency values.

The Czech acceptance level of \( \pm 3\% \) is evidently stricter than the levels used within the ESTRO quality assurance network (EQUAL) or the IAEA TLD postal programme (\( \pm 5\% \)) [4,8]. This is justified by the better capability of the small national network to repeat the audit promptly or to investigate the situation thoroughly if necessary.

If the deviation is within the acceptance level, the full detailed results are mailed to the chief physicist of the audited radiotherapy centre. For a minor deviation the chief physicist is informed that a minor deviation was detected and that the audit will be repeated shortly. If a major deviation is found, the radiotherapy centre is informed, and as a consequence, it is its duty to investigate the situation, explain a possible cause for the discrepancy and order a repeated TLD audit on its own costs. Deviations exceeding \( \pm 10\% \) are reported to the SONS immediately, which can execute proper sanctions towards the radiotherapy centre. A detailed on-site audit by EAG usually is commanded and activities of the radiotherapy centre can be suspended temporarily.

Except major and emergency deviations, results of all performed TLD audits are mailed to the SONS monthly for information.

The relevant reports to SONS contain the results of the basic audit only. For the advanced audit there are no sanctions used towards the radiotherapy centre at present time. The present practice is such that if some deviations exceeding the acceptance level are found, they are reported to the chief physicist who is asked to investigate the situation and check the treatment planning system including dosimetric data.

5. Results

5.1. Summary of measurements

Between February 1997 and December 2001 all the 34 Czech radiotherapy centres have undergone the basic TLD audit for all their clinically used beams at least three times. Those showing some dosimetric discrepancies have been audited more frequently. A total of 362 checks of photon and electron beams were performed in this way.

The advanced audit as a pilot study was conducted for ten radiotherapy centres in 1999–2001. Within the pilot study 11 TPS (seven different types) were tested for application of

### Table 2

Irradiation set-ups tested within the advanced TLD audit

<table>
<thead>
<tr>
<th>Set-up</th>
<th>Description</th>
<th>Position of TLD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>On central beam axis</td>
</tr>
<tr>
<td>G1</td>
<td>Reference conditions (10 × 10 cm²)</td>
<td>Yes</td>
</tr>
<tr>
<td>G2</td>
<td>Asymmetrical field (5 and 2) × 10 cm² either with asymmetrical collimator or with a block</td>
<td>Yes</td>
</tr>
<tr>
<td>G3</td>
<td>Rectangular field (9 × 15 cm²)</td>
<td>Yes</td>
</tr>
<tr>
<td>G4</td>
<td>Wedge fields (9W × 15 cm², wedges from 15° to 60°)</td>
<td>Yes</td>
</tr>
<tr>
<td>G5</td>
<td>Oblique incidence (15 × 15 cm², depth of 8.3 cm on central beam axis)</td>
<td>Yes</td>
</tr>
<tr>
<td>G6</td>
<td>Open large field (15 × 15 cm², depth of 10 cm)</td>
<td>Yes</td>
</tr>
<tr>
<td>G7</td>
<td>Inhomogeneities (15 × 15 cm², depth of 10 cm)</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### Table 3

Particular TPS, irradiation radiotherapy machines and beams within the pilot study

<table>
<thead>
<tr>
<th>Treatment planning system</th>
<th>Irradiation machine</th>
<th>Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>CadPlan (1)</td>
<td>Clinac 600C</td>
<td>X-rays of 6 MV</td>
</tr>
<tr>
<td>CadPlan (2)</td>
<td>Clinac 2100C</td>
<td>X-rays of 6 MV</td>
</tr>
<tr>
<td>PlanW (1)a</td>
<td>Philips SL-20</td>
<td>X-rays of 6 MV</td>
</tr>
<tr>
<td>PlanW (2)</td>
<td>Clinac 2100C</td>
<td>X-rays of 6 MV</td>
</tr>
<tr>
<td>PlanW (3)</td>
<td>Chisobalt</td>
<td>60Co</td>
</tr>
<tr>
<td>PlanW (4)</td>
<td>Teragam</td>
<td>60Co</td>
</tr>
<tr>
<td>CMS-Focusa</td>
<td>Philips SL-20</td>
<td>X-rays of 6 MV</td>
</tr>
<tr>
<td>Theraplan</td>
<td>Theratron 1000</td>
<td>60Co</td>
</tr>
<tr>
<td>Target 2</td>
<td>Orion 5</td>
<td>X-rays of 5 MV</td>
</tr>
<tr>
<td>Prowess 3000</td>
<td>Teragam</td>
<td>60Co</td>
</tr>
<tr>
<td>Multidata</td>
<td>Chisostat</td>
<td>60Co</td>
</tr>
</tbody>
</table>

a The same radiotherapy centre.
cobalt and X-ray beams. More details are presented in Table 3.

5.2. Results of the basic TLD audit

The results are presented in Fig. 2, which shows results of all the performed audits between 1997 and 2001. Results in terms of the $\Delta D$ (%) distribution related to single years are distinguished. For the total number of beams, the mean $m$ for the $\Delta D$ (%) distribution is $-0.04$ and the standard deviation $s$ is $2.83$. The emergency level was exceeded for four machines: one $^{137}$Cs unit, two $^{60}$Co unit and one betatron (19 MV X-ray beam). It is obvious that no emergency level was detected in the course of the last 2 years.

5.3. Results of the advanced TLD audit

The results obtained within the pilot study are reported in Tables 4–6. Table 2 summarises the irradiation geometries that were tested. The reported deviations can be due to a human, machine, calibration, geometry and other errors, and they might not be directly connected with the TPS algorithm. Since this was just pilot study no randomised experiments have been so far performed to distinguish source of errors. For simplicity of reporting we refer to TPS, but we have in mind users of these TPSs.

5.3.1. Results for reference set-up, asymmetrical and rectangular fields

Results of these measurements on central beam axis are presented in Table 4.

For the simplest irradiation set-up (reference conditions), all the systems conform with the condition $|\Delta D| \leq 3\%$ with the exception of one user of the PlanW systems (PlanW (4)), where the detected deviation was $-3.2\%$.

Results for the asymmetric field contain one major deviation of $7.9\%$ that was found for the user of Prowess 3000 system. A minor deviation of $-3.3\%$ was found for PlanW (4). Other systems complied.

In case of the rectangular field, all results lay inside the acceptance interval. Though the PlanW (4) was very close to the limit again.

5.3.2. Results for wedge fields

A total of 44 wedge fields were checked that means a total of 132 TLD capsules, 44 of them on central beam axis, 88 off central beam axis. The results are reported in Table 5. Taking into account all the 132 measurements, the mean is 0.0 and the standard deviation is 2.7. A total of 89% of the on axis measurements conformed with the condition of $|\Delta D| \leq 3\%$. In case of off axis measurements it was 78% of them that conformed.

It is obvious that deviations outside the acceptance level were more frequent for off axis measurements. There were even found a few emergency and some major deviations. They were detected for PlanW (4) (wedges of 30° and 45°, $\Delta D$ of $-11.7$ and $-8.2\%$) and Theraplan (wedge of 60°, $\Delta D = 7.1\%$). Minor deviations were found for systems Prowess 3000, PlanW, Theraplan, Target 2 and CMS-Focus. No deviations exceeding the acceptance limit were found for CadPlan and Multidata.

5.3.3. Results for oblique incidence, open large field and inhomogeneities

The results are reported in Table 6. For the oblique incidence set-up, a few minor positive deviations were found. They are referred to PlanW (4), one of CadPlans and Target 2.

One case of a minor deviation was found for the set-up...
with large field also. It refers to PlanW (4) system both for on and off axis measurements. As the field was symmetric, the deviations for L and R dosimeter were taken in average.

Major positive deviations were frequent for the set-up with inhomogeneities, especially for off axis measurements. They were detected for three of PlanW systems. Minor deviations were detected for all PlanW systems, Theraplan and CadPlan (2). No deviations exceeding the acceptance limit were found for one of the CadPlan (1), CMS-Focus and Multidata.

5.3.4. Results for particular TPS

Excellent results were obtained for the Multidata system, where the quality of $|\Delta_0| \leq 3\%$ was achieved for all irradiation set-ups. Similarly very good results were achieved for CMS-Focus (only one case of minor deviation detected) and CadPlan systems (one of them complied with $|\Delta_0| \leq 3\%$ wholly, another one showed three minor deviations maximally up to 4%).

Results with a few minor deviations were reported for Target 2 (seven cases maximally up to 4.9%).

Both major and minor deviations were found for Theraplan (three cases maximally up to 7.1%), Prowess 3000 (four cases maximally up to 7.9%), PlanW (1) (two cases up to 6.2%), PlanW (2) (nine cases up to 8.7%), PlanW (3) (two cases up to 6%) and PlanW (4) (11 cases up to 8.2%).

One emergency deviation was detected for PlanW (4) (−11.7% for a wedge field).

6. Discussion

6.1. Analysis of deviations exceeding acceptance level for basic TLD audit

The deviations exceeding the emergency level for the basic TLD audit were carefully investigated. Shortly after the TLD audit on-site measurements were performed. They proved that the discrepancies were caused by mistakes by local physicists or wrong conditions of the outdated machines. The latter one was obvious especially for the betatron where keeping it stable was evidently difficult.

Table 4

<table>
<thead>
<tr>
<th>TPS</th>
<th>G1 (reference conditions)</th>
<th>G2 (asymmetrical field)</th>
<th>G3 (rectangular field)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CadPlan (1)</td>
<td>0.5</td>
<td>1.3</td>
<td>_a</td>
</tr>
<tr>
<td>CadPlan (2)</td>
<td>1.2</td>
<td>0.7</td>
<td>1.9</td>
</tr>
<tr>
<td>PlanW (1)</td>
<td>1.7</td>
<td>1.9</td>
<td>1.7</td>
</tr>
<tr>
<td>PlanW (2)</td>
<td>−0.3</td>
<td>0.3</td>
<td>1.3</td>
</tr>
<tr>
<td>PlanW (3)</td>
<td>0.7</td>
<td>1.9</td>
<td>0.0</td>
</tr>
<tr>
<td>PlanW (4)</td>
<td>−3.2</td>
<td>−3.3</td>
<td>−2.8</td>
</tr>
<tr>
<td>CMS-Focus</td>
<td>−0.4</td>
<td>1.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Theraplan</td>
<td>0.2</td>
<td>_a</td>
<td>−1.2</td>
</tr>
<tr>
<td>Target 2</td>
<td>2.7</td>
<td>_a</td>
<td>2.3</td>
</tr>
<tr>
<td>Prowess 3000</td>
<td>−0.9</td>
<td>7.9</td>
<td>−2.0</td>
</tr>
<tr>
<td>Multidata</td>
<td>0.6</td>
<td>−1.6</td>
<td>0.9</td>
</tr>
</tbody>
</table>

_a The TPS user did not performed the test.

Table 5

<table>
<thead>
<tr>
<th>TPS</th>
<th>Wedge 15°</th>
<th>Wedge 30°</th>
<th>Wedge 45°</th>
<th>Wedge 60°</th>
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<td>L M R</td>
<td>L M R</td>
<td>L M R</td>
<td>L M R</td>
</tr>
<tr>
<td>CadPlan (1)</td>
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<td>_b _b</td>
<td>_b _b</td>
<td>_b _b</td>
</tr>
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<td>1.9 2.8</td>
<td>1.2 1.7</td>
<td>0.6 1.0</td>
</tr>
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<td>PlanW (1)</td>
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<td>_b _b</td>
<td>_b _b</td>
<td>_b _b</td>
</tr>
<tr>
<td>PlanW (2)</td>
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<td>_b _b</td>
<td>_b _b</td>
<td>_b _b</td>
</tr>
<tr>
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<td>1.3 2.8</td>
<td>0.1 0.1</td>
<td>0.6 0.6</td>
</tr>
<tr>
<td>PlanW (4)</td>
<td>_b _b</td>
<td>_b _b</td>
<td>_b _b</td>
<td>_b _b</td>
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<tr>
<td>CMS-Focus</td>
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<td>_b _b</td>
<td>_b _b</td>
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<td>1.1 1.1</td>
<td>1.3 1.3</td>
<td>1.3 1.3</td>
</tr>
</tbody>
</table>

a M, measurement on central beam axis; L, measurement left off central beam axis – thicker side of the wedge; and R, measurement right off central beam axis – thinner side of the wedge.

b The TPS user did not perform the test.
The exceeded emergency levels were noted during the period of 1997–1999 and since then the situation has improved, because some outdated machines have already been eliminated from the clinical use.

The cases of major and minor deviations usually are resolved by repeating of the TLD audit. It stimulates the radiotherapy centres to control their dosimetry and to perform some remedies if necessary. Results of the repeated audit typically comply with the acceptance level thus.

6.2. Analysis of deviations exceeding acceptance level for advanced TLD audit

6.2.1. Analysis of deviations for reference set-up, asymmetrical and rectangular fields

The systematic minor deviations for the PlanW (4) system indicate a possible incorrect beam calibration or incorrect dosimetric data inserted into the planning system.

Protocol provided by the Prowess 3000 user indicated that the major deviation found for the asymmetrical field probably was associated with the applied inaccurate correction factor for absorption in the tray that was used as a block support.

6.2.2. Analysis of deviations for wedge fields

In general, the detected deviations can be associated with uncertainties in determination of the wedge attenuation coefficients. Any difference between real and TPS calculated beam profile can influence the deviation between calculated and measured values in the off axis points. Besides that, it can be related also to uncertainties connected with the accuracy of the phantom geometrical position during the irradiation.

In order to unravel the reason for emergency and major deviations found for PlanW (4), calculated isodose curves were carefully investigated. The TPS calculated curves showed differences up to 7% in some points compared to theoretically expected values for a $^{60}$Co beam, standardized wedge, given SSD and given depth. It might be the coherence, why the planned doses were higher than those delivered to TLDs in fact. Consequently, the deviations worked out with negative sign. Though it did not explain the factual emergency and major deviations quite.

In case of minor deviations found for the other systems it was difficult to distinguish, if the deviations were related to some wrong positioning or some dosimetric discrepancies.

6.2.3. Analysis of deviations for oblique incidence, open large field and inhomogeneities

The deviations related to the oblique incidence set-up can be associated with wrong geometrical set-up. The discrepancy can also be associated with the known fact about the shortcomings of some calculation algorithms that do not take into account the change in scatter with lateral position and also with depth [14]. The few minor deviations detected for the oblique incidence were difficult to interpret in this way though.

The minor deviations found for the large open field for the PlanW (4) could be connected with some discrepancies in depth data dose or output factor.

The discrepancies associated with the inhomogeneities can be connected with incorrect calibration curve for electron density calculation from CT data that influences calculated attenuation coefficients. It may relate for PlanW systems that systematically showed positive deviations (minor and major) for off axis measurements where the isodose curves were shaped by inhomogeneities presence. For PlanW (2) system, there was a probable set-up mistake in addition as the local physicist reported.

6.2.4. Analysis of deviations for particular TPS

The pilot study revealed that the measured deviations are not connected particularly with a certain type of treatment planning system. The best results were achieved for the large radiotherapy centres that are adequately equipped to perform high quality radiotherapy. Such centres often use
efficient systems like CadPlan or CMS-Focus that have online connection to the CT, simulator and verification system. These centres also have good dosimetric equipment and usually a team of experienced medical physicists with adequate training to perform a good commissioning of treatment planning systems.

Results obtained for PlanW systems present an example of quality differences among radiotherapy centres. PlanW (4), for which a few major and emergency deviations were measured, comes from a typical small regional radiotherapy centre equipped with one $^{60}$Co unit and one $^{137}$Cs unit. In contrast, PlanW (3), which showed better results, is used in a large centre with better equipment and experience. This shows that the deviations are more related to the level of clinical dosimetry than to TPS algorithm.

Dates of the last software upgrade for the individual TPS were considered also but there was not found any relation to the results. For instance PlanW (4) with the worst results had the last software upgrade in 1999 alike PlanW (1) and PlanW (3) (they all have the same software version). This supports the hypothesis about quality differences among Czech radiotherapy centres also.

As for discrepancies connected only with the treatment planning system without any human influence, the minor and major deviations systematically detected for all PlanW systems for off axis measurements for the set-up with inhomogeneities may be considered in this way.

However, to distinguish individual sources of errors, included in measured deviations, it will be necessary to run randomised experiments to prove that some algorithm are less precise than others.

7. Conclusions

The results of the TLD QA network show the importance of external audits in radiotherapy centres. The regular checks lead to improvement of clinical dosimetry, as it is evident especially for the basic TLD audit where presently 90% of the results are within the $\pm 3\%$ limit. Comparing this with results of other postal TLD networks, e.g. IAEA, which provides the TLD audits worldwide, noted that 81% of the institutions participating regularly in the audits have results within the $\pm 5\%$ limit [9]. Within the frame of the EQUAL programme, which was introduced for European countries, 97% of the outputs in reference conditions showed deviations within the level of $\pm 5\%$ [4]. If the limit of $\pm 5\%$ was used in the Czech TLD network, 95% of the results would be within the limit, which makes the Czech situation better than the worldwide average but slightly worse than the European or rather EU average (most of participants were from EU countries).

The method of the TLD advanced audit showed its potentials to detect major deviations in non-reference conditions that can be caused both by mistakes in clinical dosimetry and treatment planning. It is expected that the advanced mode of the TLD audit will be used as a strict tool for purposes of state supervision in the Czech Republic in the near future. At present it is operated as a pilot study and that gives the radiotherapy centres the opportunity to become familiar with the method and to be prepared for a new situation.

Some of the treatment planning systems used in the Czech Republic do not have all necessary software modules to fulfill up to date requirements for high quality treatment planning. Their qualitative variety is connected with the non-existence of an appropriate national recommendation, which have to state basic requirements for treatment planning. Consequently, the users could appoint different criterions for treatment planning system choice. The national recommendation for treatment planning systems is being prepared. The intended strict operation of the advanced TLD audit is on condition of existence of the national recommendation on treatment planning systems.

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References


