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Review

The role of SSDL in quality assurance in radiotherapy

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ABSTRACT

This paper describes the role of the Polish Secondary Standard Dosimetry Laboratory (SSDL) in quality assurance in radiotherapy by means of providing calibration of ionisation chambers, TLD postal dosimetry audits and end-to-end audits for radiation therapy. A historical review of the methods and results are presented. The influence of the SSDL in Warsaw on radiation protection of patients in Poland is discussed. The International Atomic Energy Agency together with World Health Organisation (IAEA/WHO), through its network of SSDLs around the world, propagates newly developed methods for calibration and auditing. Suitable high quality equipment was provided by the IAEA, as well as special materials and technical support to the SSDL in Warsaw. The activity of the SSDL and the services provided for Polish radiotherapy centres have resulted in a reduction of discrepancies between planned doses and doses delivered to patients. The newly tested IAEA methods of end-to-end on-site dosimetry audits allow for monitoring and improving the quality of IMRT in Poland. The traceability of standards used for the calibration of therapy level dosimeters from Polish radiotherapy centres is assured by the IAEA dosimetry laboratory. The consistency of methods performed in the Polish SSDL with the ISO:17025 norm is supervised by the Polish Centre for Accreditation – a member of International Laboratory Accreditation Cooperation (ILAC), for calibration and testing. Due to the rapid technological development of radiotherapy, special attention has to be paid to newly developed methods for dosimetry auditing and institutions which provide services for assuring radiation safety of patients.

1. Introduction

The Polish Secondary Standard Dosimetry Laboratory of in Warsaw was created in 1966. It is a continuation of the Physics Laboratory organised in 1934 according to the plans of Maria Skłodowska-Curie, founder of the Radium Institute opened in 1932. Since its beginnings, the Physics Laboratory was devoted to developing methods of measurement of radiation delivered to patients treated in a clinic of the Radium Institute as well as to the control of radiation delivery in other hospitals in Poland. This task was performed by the X-Ray and Radioactive Substances Calibration Laboratory opened at the Physics Department in 1937 according to governmental regulation. WW2 put an end to this activity which was re-established in 1951, when the Central Laboratory of Radiological Measurement was created. In 1966, the laboratory was upgraded and given the status of a Secondary Standard Dosimetry Laboratory, approved by Główny Urząd Miar (GUM) – Polish national metrology organisation. In 1988, the SSDL in Warsaw joined the IAEA/WHO (International Atomic Energy Agency/World Health Organisation) network of SSDLs, and provides calibration of therapy level dosimeters with cylindrical or plane-parallel ionisation chambers in a Co60 beam, and for Ir192 HDR brachytherapy well chambers. The present equipment of the SSDL in Warsaw was acquired with significant support from the IAEA. Since 2014, the SDDL in Warsaw is an accredited calibration laboratory according to the ISO:17025 norm, and is annually audited by the Polish Centre for Accreditation – a member of ILAC (International Laboratory Accreditation Cooperation) association. Accreditation, in accordance to the ISO:17025 norm, was also obtained for the postal TLD dosimetry audits, which are performed annually in all Polish radiotherapy centres. Due to the activity related to the dosimetry audits, the SSDL in Warsaw collects detailed data about radiation machines, beams and radiation

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Fig. 1. FIMEL-PCL3 automatic TLD reader.gr1

sources, used both for tele- and brachytherapy in Poland, and maintains such a database. Currently, the methods of auditing new and complex techniques, such as intensity modulated radiation therapy (IMRT) modality, are introduced and tested in collaboration with the IAEA. The tested audit methods were developed within the framework of the IAEA projects: CRP E2.40.16 "Development of Quality Audits for Radiotherapy Dosimetry for Complex Treatment Techniques" and CRP E2.40.18 "Development of Quality Audits for Advanced Technology (IMRT) in Radiotherapy Dose Delivery".

2. Materials

The SSDL in Warsaw is equipped with a Theratron 780E Co60 unit (MDS Nordion) used exclusively for the calibration of therapy level dosimeters or for the irradiation of the reference TLD samples. For the calibration of the well chambers, the microSeletron (Nucletron) afterloader with Iridium 192 source is used. Reference level dosimeters: Keithley 6517 (USA) and Fluke 35040 (USA), with Farmer type cylindrical chambers, as well as the Supermax 90018 (SunNuclear, USA) electrometer with a PTW 35004 (Germany) well chamber are used as standards. The FIMEL-PCL3 (France) automatic reader (Fig. 1) is used for readout of the MT-N type TLD (LiF:Mg,Ti) samples, which are irradiated in the framework of the postal dosimetry audits in Polish radiotherapy facilities.

For complex and advanced methods of irradiation like intensity modulated radiation therapy (IMRT), specially designed phantoms and new detectors are used in dosimetry audits. The Gafchromic (Ashland, USA) EBT3 radiochromic films have been introduced. The films are digitised with an Epson 10000XL Perfection (Seiko, Japan) flat-bed scanner. The FilmQA Pro (Ashland, USA) and home-made three-colour film calibration software was used in the determination of dose distributions from films irradiated according to the on-site end-to-end dosimetry audits.

CIRS IMRT thorax phantom – model 002LFC (Figs. 2 and 3) was used for on-site audits of 3D conformal teleradiotherapy techniques. A polystyrene phantom with bone and lung tissue equivalent slabs, designed by the IAEA within the IAEA project CRP E2.40.16, in which film detectors, the TLD dosimeters and a cylindrical ion chamber can be placed [1], was used for development of auditing methodology for small fields. For pilot study of dosimetry audits in advanced IMRT techniques, a phantom (Figs. 4 and 5) made within the IAEA project CRP E2.40.18 [1] was used by the SSDL in Warsaw [2].

Fig. 2. CIRS IMRT thorax phantom – model 002LFC used for on-site audits of 3D conformal teleradiotherapy techniques.gr2

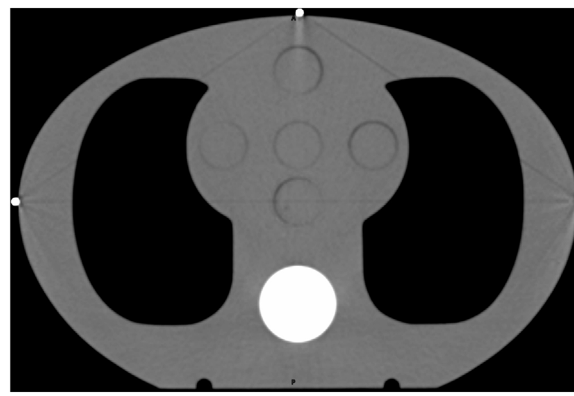

Fig. 3. CT scan of CIRS IMRT thorax phantom – model 002LFC used for on-site audits of 3D conformal teleradiotherapy techniques.gr3

Fig. 4. The phantom used for auditing with an encapsulated adaptor (aside) for films and TLD capsules [2].gr4

3. Methods

3.1. Calibration

At the SSDL in Warsaw, the calibrations are performed in a Co60 beam, in terms of the absorbed dose to water, according to the IAEA TRS-398 [3] code of practice. The calibration coefficients of the user's dosimeters are determined with the substitution method using the reference SSDL equipment (national secondary standard). In substitution method the standard is used for dose determina-

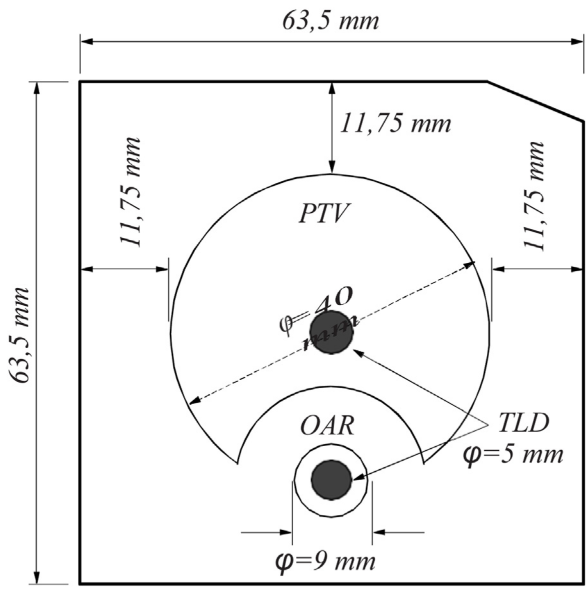

Fig. 5. Dimensions of the adaptor for films and for TLDs. The adaptor with PTV and OAR insets was encapsulated in the phantom used for auditing.gr5

tion in a water phantom and then the calibration coefficient is determined after replacing standard with calibrated chamber. The laboratory calibrates all types of cylindrical ionisation chambers, as well as the most popular plane-parallel types of chambers (Markus, Roos). Practically, all of the dosimeters used in Polish hospitals are calibrated in the SSDL in Warsaw. The SSDL reference electrometers and chambers are regularly calibrated in laboratories which are participants of the Comité International des Poids et Mesures (CIPM) Mutual Recognition Arrangement (MRA) mainly at the IAEA (Austria), at the PTB (Germany) or at the GUM (Poland) depending on the type of a standard. Therefore traceability to the primary dosimetry standard is assured.

3.2. Dosimetry audits

Since 1991, the SSDL carries out TLD postal dosimetry audits in all Polish radiotherapy centres. The audits are performed annually. Initially, the audits were carried out in reference conditions only ($10 \times 10 cm^2$, 10 cm depth), but since 2004, they were carried out mostly in non-reference conditions.

Over the last 7 years, several dosimetry audits methods, including the "end-to-end" type, were introduced and tested by the SSDL in Warsaw for quality evaluation of the 3D conformal radiotherapy (3DCRT) or IMRT technique performance in Polish oncology centres.

The method for auditing the 3DCRT was based on the IAEA-TECDOC-1583 [4] report and was developed and tested within the framework of the CRP E2.40.13 project "Development of procedures for dosimetry calculation in radiotherapy". In the audit, 8 planned cases with gradually increased complexity of the beam arrangement were created for the CIRS IMRT thorax phantom (Figs. 2 and 3) [5].

The methods of the quality audit for photon beams in the presence of heterogeneities was tested using a polystyrene phantom with bone and lung tissue equivalent slabs, in which the TLD dosimeters and a cylindrical ion chamber were placed [6]. The 2D profile quality audit, for small size photon MLC shaped fields was also tested using the same phantom, with specially designed inserts for films.

Within the framework of the IAEA projects: CRP E2.40.16 Development of Quality Audits for Radiotherapy Dosimetry for Complex Treatment Techniques and CRP E2.40.18 Development of Quality Audits for Advanced Technology (IMRT) in Radiotherapy Dose Delivery, a four step audit was tested [7].

The first step, consisted of the quality audit for dose rate dependence of small size fields shaped with MLC performed in Polish radiotherapy centres [8]. This type of MLC audit does not require any measurements to be performed on the treatment machine, because the calculation results obtained from audited treatment planning systems (TPS) were compared with the published benchmark data from The Radiological Physics Center (RPC) in Houston, USA (currently IROC) [9,10].

In the second step, the performance of MLC was verified for a selected treatment machine in each of the Polish teleradiotherapy departments. Gafchromic EBT2 films with asymmetrical clear polyester lamination of an working layer were sent to the participants in postal audit for irradiation with a so called "picket-fence" pattern formed with the MLC [11]. The films were evaluated with FilmQA Pro (Ashland, USA) software to detect any traces of geometrical inconsistency in MLC performance. Clear asymmetrical polyester lamination allowed to obtain sharp images of picket-fence patterns due to low light scattering properties and because of bending of the film surface over the scanner glass.

In the third step, the Gafchromic EBT3 and TLDs were used in an end-to-end audit of the IMRT technique on the treatment units for which the MLC was tested in the former audit [2]. A specially designed cubic polystyrene phantom (Fig. 4) with an adaptor for films and a planning target volume (PTV) and an organ at risk (OAR) inserts (Fig. 5) made within the IAEA project CRP E2.40.18 was used [1]. The films were positioned in the adapter and TLD capsules were placed in the PTV and OAR, to record the total dose distributions and point dose due to irradiation of the IMRT plan created on the basis of computer tomography (CT) of the phantom. A chosen single IMRT field from the treatment plan was also used for irradiation of the film placed between slabs made of water-equivalent material to verify MLC only dependent dose distribution. EBT3 films with symmetrical clear polyester lamination of the working layer and with an anti-Newton ring coating allowed to obtain high quality images of the dose distribution.

The phantom followed the patient path in each audited radiotherapy centre including pretreatment verification of the planned dose distribution. The films and TLDs were evaluated in the SSDL in Warsaw and compared with the results of TPS calculations in terms of dose difference or the gamma index passing rate (3 mm/3% of the maximum dose).

4. Results

The results of TLD postal dosimetry have improved considerably over the years. Therefore, the initial tolerance level of ±5% was decreased to that of ±3.5%, which is the tolerance level adopted by the IAEA only for SSDLs [12].

In the quality audit for photon beams in the presence of heterogeneities, 10 departments were examined, which was at that time almost 1/3 of their total number of departments in Poland. The discrepancies between the TPS calculations and the TLD measurements were within a ±5% range under the bone or lung heterogeneities, and did not exceed ±10% for the TLD placed off-axis in lung equivalent media [6].

All Polish radiotherapy centres took part in the quality audit for dose rate dependence of small fields shaped with MLC. For fields larger than $2 \times 2 cm^2$, the resulting calculations differed less than 4% from the benchmark data [9,10]. For $2 \times 2 cm^2$ fields, the differences between the calculated and measured output factors often exceeded 5%, but were still below 10% [13,14].

Thirty-three Polish radiotherapy centres took part in the audit of MLC performance. The discrepancies between the stripe positions of the picket-fence pattern recorded on films and that which had been expected were in the range of ±1.2 mm (maximum difference). Position off-sets of a centre of each individual leaf pair aperture was in the range of −0.5 mm to 0.5 mm from the centres of the picket-fence stripes.

Twelve centres equipped with MLC participated in the end-to-end audit of the IMRT. In the gamma index evaluation of single field dose distributions, the passing rate was higher than 98.5% (at 3 mm/3% of the maximum dose) in all cases. For the multi-field dose distribution of IMRT plans, the gamma index passing rate (at 3 mm/3% of the maximum dose) was higher than 95% in 11 cases. Discrepancies between the doses measured with TLD and that calculated with TPS were of below 5% in 10 centres for the PTV, and in 9 centres for the OAR, and are in accordance with the results obtained with radiochromic films [15].

5. Discussion and conclusions

The service provided by the SSDL in Warsaw is highly evaluated by the participants of the audits performed and by the customers who calibrate their dosimeters there. Continuous collaboration of the SSDL in Warsaw with the IAEA, by means of participation in coordinated research projects of the IAEA, results in the dissemination of the newest dosimetry auditing techniques in Poland. The aim of the participation of the SSDL in the IAEA audit pilot studies was twofold: firstly, it was an opportunity to verify the capabilities of the SSDL in Warsaw, and secondly, it allowed for the laboratory to test the methodology and to include new auditing methods in the routine service of the SSDL. Polish radiotherapy centres voluntarily participate in pilot studies of new auditing methodologies. The results of the pilot studies performed in Polish radiotherapy centres are published as local results, and are included in the IAEA publications which usually contain data from RT centres in different member states. The publication describing the pilot audit studies performed, helps the participants to interpret locally obtained results and to prove the efficacy of the measures applied, in order to achieve a high quality of the radiotherapy services provided. In Poland, participation in annual dosimetry audit service is mandatory. Currently, the SSDL in Warsaw is the only institution providing audits for radiotherapy in Poland. Thanks to the collaboration with the IAEA and the accreditation upheld for auditing and calibrations, the SSDL in Warsaw assures traceability for doses delivered to patients during radiotherapy. Furthermore, the number of radiotherapy centres in Poland is constantly growing, hence the number of accelerators rises every year. It is expected from newly opening RT centres to undergo an independent dosimetry audit before they start to carry out clinical operation. The authors appreciate that such steps are taken and consider that it is linked to the successful auditing service provided by the SSDL in Warsaw over the years. It is also an expression of trust that the calibrations and audit services provided by the SSDL in Warsaw can be depended on. Every year, the SSDL is audited by the accreditation institution according to the ISO-17025 norm. The activity of the SSDLs, supported by IAEA methodology and resources, helps to assure radiation safety of patients worldwide.

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