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Original Research Article

Dosimetry audit in radiotherapy – key role in safety culture

Katia Sergieva

Queen Giovanna University Hospital, Radiotherapy Department, Sofia, Bulgaria

E- mail address of main author: sergievakm@abv.bg

Abstract

During the International Conference on Radiation Protection in Medicine held in Bonn in 2012, several areas for improvement were identified and one of them is radiation safety culture. The effectiveness of the safety culture can be improved if dosimetry audit is performed on the radiotherapy process. IAEA Dosimetry Laboratory have been used the radio-photoluminescence dosimetry (RPLD) systems with glass dosimeters to perform postal dosimetry audit since 2017 to check the dose delivered by hospital' radiotherapy unit in the reference conditions. In the period 2017-2019 12 /twelve/ Bulgarian radiotherapy centres participated in the IAEA/WHO Postal Dose Audit Service with (RPLD). The number of checked beams was 34. The results in terms Diaea/Dstated have shown that 33 beams were within 5% acceptance level. Dosimetry audit ensure, that the correct therapeutic dose is delivered to the patients undergoing radiotherapy and play a key role in activities to create a safety culture. One important component of safety culture, particularly in the nuclear applications is radiation safety for employees and local communities, while in radiotherapy means safety of the patients and hospital staff. The good safety culture creates an environment for success and allow us to treat more patients in efficient, effective and safely manner.

Keywords: Dosimetry audit, Radiation safety, Radiotherapy, RPLD dosimetry, Safety culture

INTRODUCTION

During the International Conference on Radiation Protection in Medicine held in Bonn in 2012, several areas for improvement were identified and one of them is *radiation safety culture*. In general the "*culture is how we do things around*". International Atomic Energy Agency (IAEA) has a special definition of term "*culture*". According to the IAEA definition organizational culture is a mixture of an organization's traditions, values, attitudes and behaviour (https://gnssn.iaea.org/). Since the nuclear activities and knowledge are unique in many ways in the nuclear applications, culture is associated with term "*safety culture*" (https://www.iaea.org).

It was adopted by the IAEA in recognition of the fact that nuclear safety is strongly dependent on the actions and thoughts of the people within organization. The nuclear organizations are fully responsible to create a safety culture, working in manner of professional cooperation and communications with staff in high degree of transparency. Maintaining and improving safety culture requires continuous action and commitment. There is a need to establish a program to measure, review and audit all activities, health and safety performance against predetermined standards. The effectiveness of the safety culture can be improved if *dosimetry audit* is performed on the radiotherapy process. Something more, the radiotherapy equipment has been replaced with new state-of-the-art linear accelerators since 2011 across the country. The performing a dosimetric audit was more than necessary.

The organization and conducting of the dosimetric audit is necessary to improve the safety of patients in radiation therapy and to optimize the treatment with ionizing radiation. It is extremely important to know, that the treatment is carried out in accordance with the accepted standards, that the doses received by the patients correspond to the prescribed ones, and that the quality of the treatment process is constantly improving. The independent dosimetric audit is an effective tool for checking and improving the quality of the conducted radiotherapy practice in a given radiotherapy center. The optimal clinical outcome for any patient treated with radiation therapy critically depends on the accurate calibration of the high-energy photon beams and electrons used. Dosimetry audit is a key component in quality management programmes in radiotherapy, playing an important role in the safe implementation of new treatment modalities and techniques. (Clark et al., 2015; Thwaites, 2013; Followill et al., 2007; Izewska et al., 2000).

Dosimetric audit as a highly specialized method of verifying clinical dosimetric practice has also undergone its technological evolution in recent years. The following new forms of dosimetric audit have been developed and implemented, as pilot studies at national level or as research projects, following the high-tech development of radiotherapy equipment in the last 5 (five) years, namely: *Dosimetry audit for irregular fields shaped with an MLC high energy photons; Dosimetry audit in the presence of heterogeneities high energy photons; TLD check and film profile for small photon MLC shaped fields; Photon beam small field output factors (OF) shaped with an MLC and film quality audit for photon beam static gantry single IMRT field; TLD and film quality audit for photon beam static gantry single IMRT field; TLD and film quality audit for photon beam end-to-end IMRT treatment delivery*.

Furthermore, the licensee of the radiation therapy facilities should ensure that independent verification of the calibration of all radiation therapy equipment is performed through participation in a national, regional or international programme. (IAEA, No. SSG-46)

One of the simplest mechanisms for independent verifications of beam calibration is participation in an IAEA/WHO dosimetry postal dose quality audit with radiophotoluminescence dosimetry (RPLD) system. Due to their advantages of compactness, repeatable readout, good precision, and small fading, radiophoto-luminescence dosimeters (RPLDs) have been recently used as a dosimeter for dosimetric external audits in external radiotherapy with high-energy X - rays. (Nose et al., 2008; Mizuno et al., 2007; Mizuno et al., 2008; Mizuno et al., 2009; Rah et al., 2009; Mizuno et al., 2014; Mizuno et al., 2017).

MATERIAL AND METHODS

The IAEA/WHO dosimetry audit service is organized in 10 irradiation runs per year. Over a period of two years, each participant can be included in one of these irradiation runs. Only those institutions that agree on the terms and conditions of the IAEA/WHO postal dose audit service is provided with the dosimeters. During each irradiation window, the IAEA Dosimetry Laboratory irradiates reference dosimeters with dose D=2Gy of Co-60 beam) for every beam in participating hospitals. Therefore important that the participants keep to the fixed irradiation window. In each irradiation run, two reference institutions, such as a Primary Standards Dosimetry Laboratory (PSDL) and a leading radiotherapy centre, irradiate dosimeters with well-defined doses to provide proper quality control of the process. Dosimeters irradiated by participants should arrive at the IAEA laboratory not later than 6 weeks after irradiation. The audit results are sent to the participants within 8 weeks of receiving their irradiated dosimeters at the IAEA, depending on the queue to the readers. Participants receive individual result certificates for each beam checked. *Results within 5% limit are considered as acceptable.* (https://dosimetry-audit-networks.iaea.org)

IAEA Dosimetry Laboratory is used the RPLD system with glass dosimeters to perform postal dosimetry audit in last two years (Wesolowska et al., 2017). The principle of radio-photoluminescence (RPL) is applied to the glass dosimeter, which is one of the most excellent solid state dosimeters. The silver activated phosphate glass irradiated with ionizing radiations emits luminescence when exposed with UV light. This phenomenon is called RPL (Yamamoto et al., 2011).

A RPLD is a cumulative dosimeter usually made of silver-activated phosphate glass, in which the silver atoms act as radiophotoluminescence (RPL) centers excited by ionizing radiation. The number of RPL centers excited is proportional to the absorbed dose to the RPLD. Since the first RPLD was produced in 1949, improvements have been made to the reading precision and reliability (Tsuda, 2000).

The latest products, rod-like dosimeters of a few mm size measure absorbed dose that can be evaluated with an uncertainty of about 1% to2% (k=1) in certain conditions (Araki et al., 2003; Mizuno et al., 2008; Rah et al., 2013; Manninen et al., 2012).

A Dose Ace system consisting of GD-302M glass rods and a FDG-1000 reader from Asahi Techno Glass Corporation (ATG) is used in IAEA Dosimetry Laboratory. (See Figure 1).

The glass rods are made of silver activated phosphate glass; they are 12 mm long and 1.5 mm in diameter, with an ID number engraved on one end. The sensitive area of a dosimeter is 6 mm long. RPLDs are encapsulated in custom made watertight capsules. (See Figure 2). Each capsule has an ID number and a bar code. The

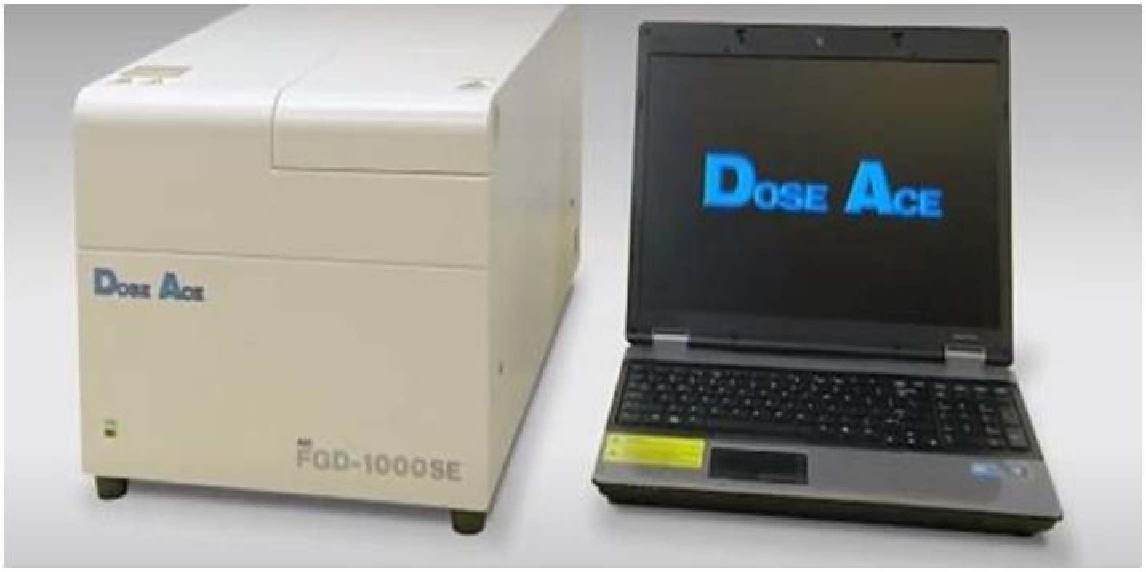

Figure 1. Dose Ace system consisting of GD-302M glass rods and a FDG-1000 reader from Asahi Techno Glass Corporation (ATG) is used in IAEA Dosimetry Laboratory.

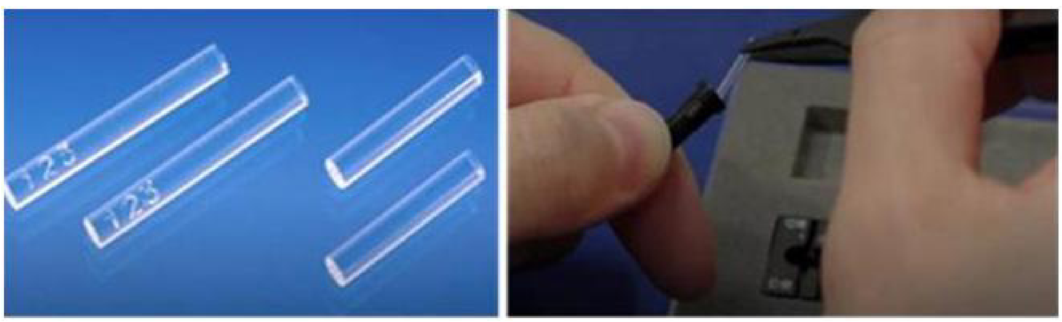

Figure 2. The glass rods- in the left and watertight capsules - in the right.

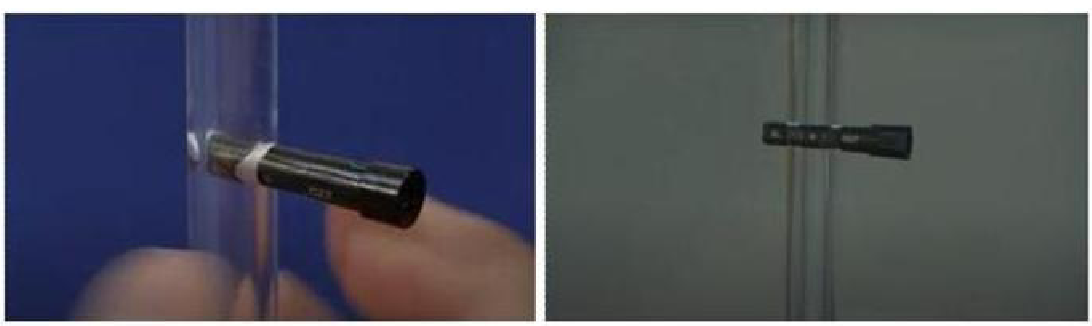

Figure 3. ID number and bar code of the capsules - in the left. The sensitive area is marked on the capsule - in the right.

sensitive area is also marked on the capsule to allow precise positioning. (See Figure 3)

The FGD-1000 reader can read up to 20 glass rods in a session of 5 min. After irradiation, the dosimeters are kept in a low humidity storage cabinet for 24 h and are then preheated to 70 ºC to stabilize the luminescence centers. RPLDs can be read several times as the read out process is not destructive (*See* Figure 4).

The IAEA/WHO postal dosimetry audit is organized in 10 irradiation runs per year. Over a period of two years,

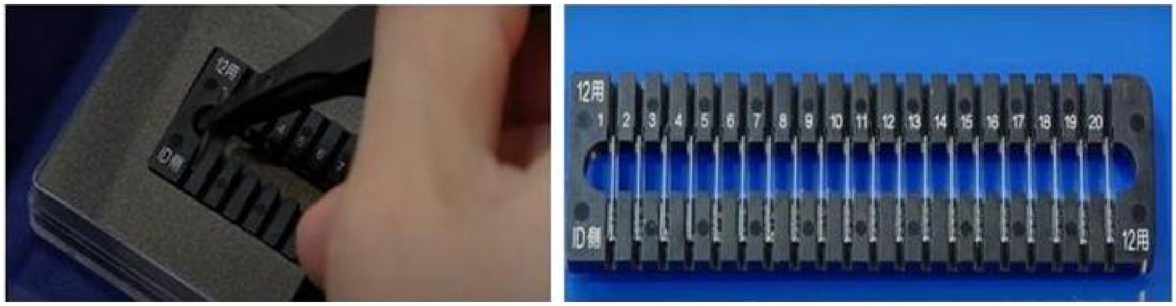

Figure 4. FGD-1000 reader can read up to 20 glass rods.

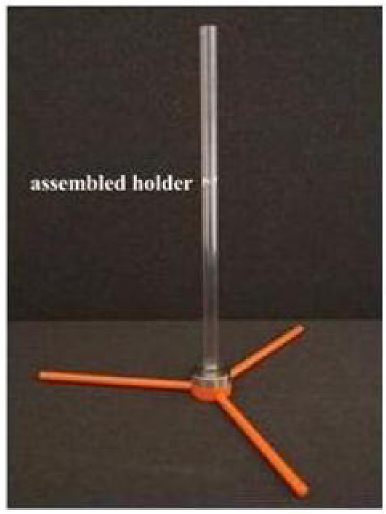

Figure 5. Assembling the IAEA standard holder for the RPLD irradiations.

each participant can be included in one of these irradiation runs. It checks the calibration of clinical photon beams (Co-60 and megavoltage beams from accelerators) in the reference conditions; 10 cm x 10 cm field size at 10 cm depth in water and source - to - surface - distance (SSD) or source - to - axis distance (SAD) delivery techniques can be set-up. (https:// dosi metry-audit networks.iaea.org/Home/PostalDose Aud itService)

The purpose of the dosimetry audit is to check the dose delivered by hospital' radiotherapy unit. The audit is performed under the following conditions for both Co-60 and megavoltage X-rays: 10 cm depth in water, 10 cm x 10 cm field size and nominal SSD or SAD distance used clinically. (https://dosimetry-audit-networks.iaea.org/Home /PostalDoseAuditService)

To realised irradiation the following steps describing in the IAEA instruction sheet should be followed:

1) Assemble the holder (Figure 5).
2) Place the holder in a water tank on the treatment table (Figure 6).
3) Set the therapy unit for a vertical beam, with a 10 cm x 10 cm field size (Figure 6).
4) Align the holder tube with the central axis of the beam (Figure 6).
5) Adjust the water level by filling the water tank exactly to the level of the top of the holder (Figure 6).
Make sure that the tube of the holder is also filled with water.
6) Adjust the table height so that the water surface is at your usual distance to the source.

The irradiation of the RPLD capsules should be perform in the following steps

1) Before irradiation recheck whether the alignment, field size, water level and distance are correct (Figure 6).
2) Insert the capsule into the hole of the holder so that the dot on the capsule is positioned in the centre of the tube (Figure 7).
3) Irradiate the RPLD capsule with the number of monitor

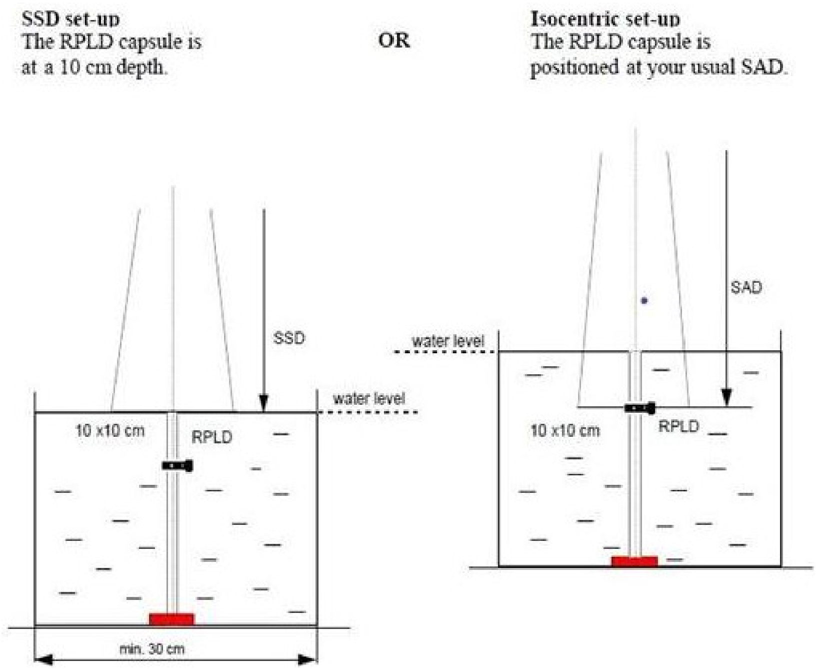

Figure 6. Two alternative geometry set-ups for the RPLD irradiation.

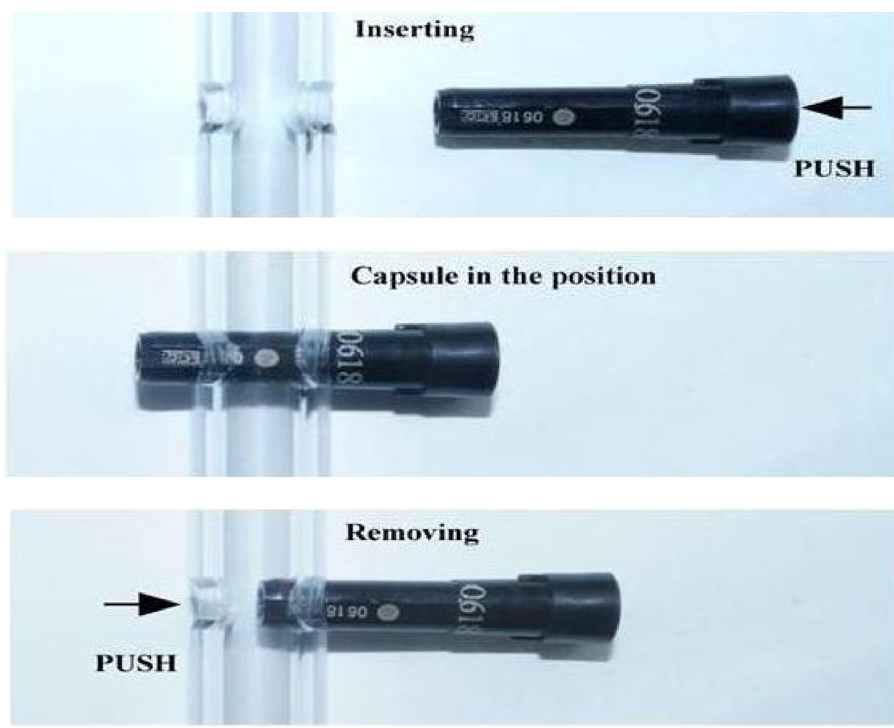

Figure 7. Different positions of the capsule with RPLD – Inserting, Capsule in the position and Removing.

units calculated above.
4) Remove the capsule from the holder (Figure 7) and wipe it dry.
5) Repeat the procedure, steps 2 to 4, for the second capsule.

The total 2 RPLD capsules per beam should be irradiated.

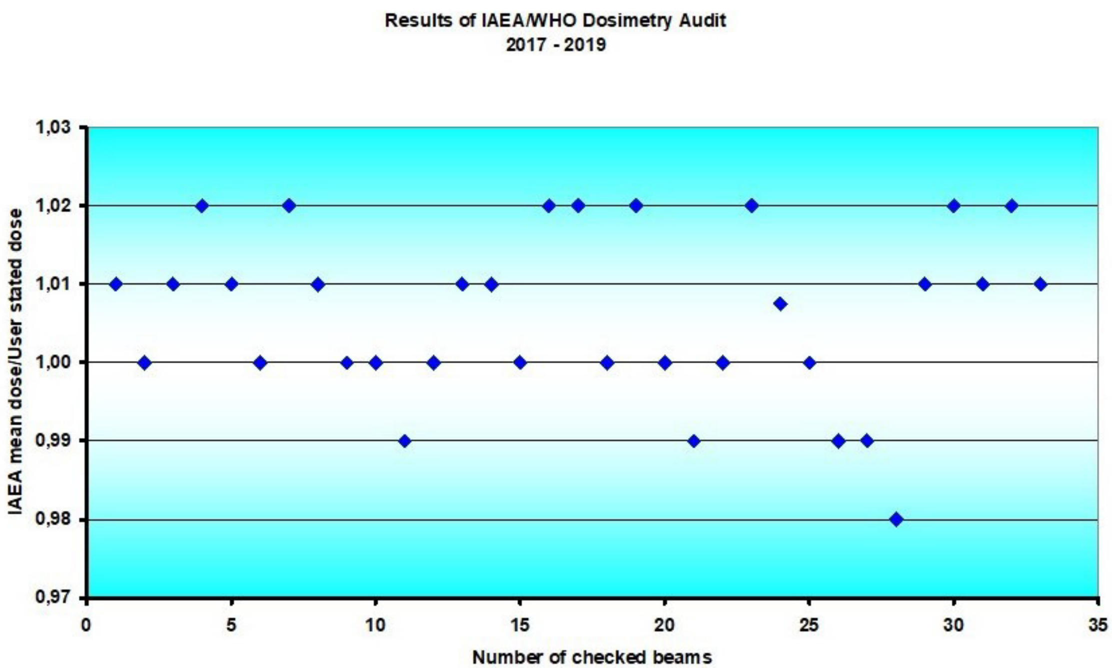

Figure 8. The results of IAEA/WHO RPLD audit 2017 – 2019.
Ratios of IAEA mean dose/stated dose
Each point in the graph represent averaged dose of 2/two/ capsules

Taking into account the following recommendations

An RPLD capsule in a small bag must not be irradiated, because it is used to record environmental influences during transport and storage; Calculation of the number of monitor units to deliver 2 Gy to a tumour, whose centre is the RPLD capsule is at 10 cm depth.

The absorbed dose to water D_w is calculated from the RPLD response registered by the is determined by the RPLD reader according to the expression:

$$D=M.N.SCF.PCF.f_{lin}.f_{fad}f_{en}f_{hol}$$

Where:
M [counts] – is the RPLD response, the mean of the readings from one dosimeter corrected for the ray readout position
N [Gy/counts] – is the calibration coefficient of the RPLD system and is defined as the inverse of RPL response per unit dose to water; N is determined for 2 Gy delivery from Co-60 beam
SCF – is individual sensitivity correction factor
PCF – is the radiation position correction factor
f_{lin} – is the non-linearity dose response correction factor
f_{en} - is the energy correction factor
f_{fad} – is the fading correction factor
f_{hol} – is the standard IAEA RPLD holder correction factor

The determination of all these factors, their values, maintenance, quality assurance and combined uncertainty of the RPLD system are comprehensively given in (Izewska, 2019).

RESULTS

In the period 2017-2019 12 /twelve/ Bulgarian radiotherapy centres participated in the IAEA/WHO Postal Dose Audit Service with (RPLD). The photon beams have been generated by the new Varian and Elekta therapy treatment machines installed in 2011 – 2017. The energy of the beams is in the range of 6 MV-15 MV. The number of checked beams was 34. The results in terms Diaea/Dstated have shown that 33 beams (97%) were within 5% acceptance level. The results are given on Figure 8. Follow up have been organized for the beam exceed the tolerance and successfully have been clarified the reason.

Dosimetric audit based on thermoluminescent dosimetry and performed in reference and non-reference conditions *on-axis* and *off-axis* of the beam represents a significant advance in clinical dosimetry during its implementation, using the new thermoluminescent dosimeter holder developed by the IAEA. Despite the fact that the radiotherapy equipment in Bulgaria was in long-term technological stagnation, the results show the ability of Bulgarian specialists to provide quality control at the current world criteria of dosimetric parameters of Co-60 systems already don't used for treatment in radiotherapy centers in the country.

The results of the RPLD audit show that all measured values of the applied dose are within ± 5%. There is a tendency to improve the accuracy, which we attribute to the in-depth knowledge, experience and skills of the staff of medical physicists due to their participation in the dosimetric audits.

DISCUSSION

Modern radiotherapy is one of most rapidly developing nuclear applications in medicine and today it is a safe and highly effective cancer treatment modality. Radiotherapy is a multi-disciplinary speciality involving complex equipment and procedures. It is recommended as part of treatment for more than 50% of cancer patients (Borras Lievens et al., 2015; Borras et al., 2015). It can be used on its own, or to complement and enhance the effects of other treatments, for example to shrink or control a cancer before and after surgery (Atun et al., 2015; Thompson et al., 2018).

Precise radiation dosimetry measurements are used to keep radiotherapy safe and effective. The need of dosimetric and geometric accuracy in radiotherapy is are well defined (IAEA Human Health Series No. 31, 2016 and ICRU report 24, 1976).

Recommendations of the International Commission of Radiation Units and Measurements (ICRU) given as early as in 1976, state that the dose delivery to the primary target should be within ±5% of the prescribed value (but in some special circumstances it should comply within ±2% to the prescribed dose to the target (ICRU report 24,1976).

Radiation beams produced by radiotherapy machines need to be calibrated. Precise measurement of the dose is crucial for this calibration, since the quality and effectiveness of the medical radiation therapy rely on their accuracy. The IAEA' dosimetry audit run jointly with the World Health Organization (WHO) since 1969 and known as IAEA/WHO Postal Dose Audit Programme. In this programme a small plastic tube containing thermoluminescent powder is irradiated to a specific dose by the medical physicist in the hospital, following the same procedure as prescribed for patient treatment. The TLDs are returned to the IAEA Dosimetry Laboratory for readout and analysis. The dose received by the TLD is compared with the intended dose stated by the hospital staff. In 2017, the IAEA Dosimetry Laboratory phased out its aging TLD systems and upgraded the lab equipment by acquiring new radiophotoluminescence dosimetry (RPLD) systems using glass dosimeters (Wesolowska et al., 2017)

Dosimetry audit in reference and non-reference conditions on and off axis was successfully introduced in some leading Bulgarian radiotherapy centers in the period 2006 – 2010 using temoluminescent dosimetry system (TLDs). The methodology of the audit is described comprehensively in 2007 (Izewska at al, 2007). The results are have already published. (Sergieva et al., 2007, Sergieva, 2008, Sergieva et al., 2019).

By the end of 2018, 2364 radiotherapy centres in 136 countries world-wide have been audited by the IAEA/WHO; 4427 machines and 5790 beams were encompassed by the audit programme (Izewska et al., 2020). The total results of 13,756 individual TLD/RPLD irradiated sets over a period of 50 years were readout, evaluated and analysed. 86% of them are within the 5% acceptance limit.

CONCLUSION

The physical and technical aspects of Quality Assurance (QA) programmes in radiotherapy include regular quality control of equipment, dosimetry of radiotherapy beams, treatment planning procedures and treatment delivery. A fundamental step in any QA programme is the *dosimetry audit* performed by an independent external body. The dosimetry audit is organized and conducted in order to increase the confidence in accuracy of clinical dosimetry and to ensure the adequacy of all performed procedures, as well as the quality of the radiotherapy equipment used for the treatment. The ultimate goal of external dosimetry quality radiotherapy audits in radiotherapy offered by the IAEA is to improve the accuracy and consistency of clinical dosimetry, in radiotherapy centres worldwide and to prevent or reduce the likelihood of errors and incidents (Izewska at al., 2007). Over the years, the audits have contributed to dosimetry practice and accuracy of dose measurements (Izewska at al., 2020). Dosimetry audit ensure, that the correct therapeutic dose is delivered to the patients undergoing radiotherapy and play a key role in activities to create a *safety culture*. One important component of safety culture, particularly in the nuclear applications is radiation safety for employees and local communities, while in radiotherapy means safety of the patients and hospital staff. The good *safety culture* creates an environment for success and allow us to treat more patients in efficient, effective and safely manner.

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