Chapter

Dosimetry Audit in Modern Radiotherapy

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Abstract

The clinical specialty of radiotherapy is an essential part of the multidisciplinary process of treatment of malignant neoplasms. Modern radiotherapy is a very complex process of treatment planning and delivery of radiation dose. Radiotherapy reached a very high degree of complexity and sophistication and expected to represent an added value for the cancer patients in terms of clinical outcomes and improved radiation protection. The concept of verifying the realized dose in the medical applications of ionizing radiation was introduced in the early 20th century shortly after the first application of X-rays for the treatment of cancer. Dosimetry audit identify areas for improvement and provide confidence in safety and efficacy, which are essential to creating a clinical environment of continuous development and improvement. Over the years, the audits have contributed to good dosimetry practice and accuracy of dose measurements in modern radiotherapy. Dosimetry audit ensures, that the correct therapeutic dose is delivered to the patients undergoing radiotherapy and play a key role in activities to create a good radiation protection and safety culture. Patient safety is of paramount importance to medical staff in radiotherapy centers and safety considerations are an element in all aspects of the day-to-day clinical activities.

Keywords: modern radiotherapy, clinical audit, dosimetry audit, radiation dosimetry measurements, radiophotoluminescent dosimeters (RPLD), quality assurance, quality managemnet

1. Introduction

The clinical specialty of radiotherapy is an essential part of the multidisciplinary process of treatment of malignant neoplasms. Moreover, oncological diseases are and will continue to be a growing health - social and socio - economic problem nationally and globally in the coming decades. The development of the clinical method of radiotherapy is based on advances in nuclear and information technology. In recent years, dramatic and I would say revolutionary changes have taken place in connection with the introduction into routine practice of a number of new methods and radiotherapy techniques for delivering of the therapeutic dose. All these innovations, set the requirements for the development of precise and clear rules, criteria and standards for the quality of the radiotherapy process as well as for conducting a regular dosimetric quality audit. Clinical audit is defined as a process of quality improvement that seeks to improve patient care and outcomes by systematically reviewing the clinical activity performed against certain formulated criteria [1].

The quality audit in radiotherapy is an independent review of the quality assurance programs, which is ideally external to the process or part of the process being audited, ie. it is performed through independent procedures and by independent staff, who are not responsible for the performance of the activities, that are the subject of the audit.

The purpose of the introduction and development of the concept of external audit in the radiotherapy is to create and maintain a consistently high quality of the treatment method. The external audit ensures, that the clinical requirements for the quality of radiotherapy are met to achieve optimal treatment in terms of maximizing the likelihood of tumor control, while maintaining low normal tissue damage within clinically acceptable levels. As part of this, the implementation of a quality assurance program will minimize errors and incidents. Most countries seek to establish transparent quality management systems in health care for a number of reasons - professional, social, financial and political. The main goal of this form of quality assurance (QA) is to improve patient care with the intention of maximizing the effect of clinical activities, minimizing harm to the individual and society as a whole.

Achieving high quality in clinical practice in general and in radiation therapy in particular is a fundamental goal. The effectiveness of the clinical method of radiotherapy depends on the exact reproducibility of the patient's position, the technical parameters of the irradiation systems and the exact dosimetric calibration of the used photon or electron beams of radiation, which are subject to international standards. The technical achievements and the conducted clinical studies impose the need of quality control programs and respectively external dosimetric audit of the radiation therapy process. This has led to the development and publication of a large number of international recommendations. The aim is to provide reliable, effective and precise radiation therapy. One of the key element is the organization and conducting of dosimetry audit in modern radiation therapy.

2. Modern radiotherapy

Cancer is a leading cause of death worldwide, accounting for nearly 10 million deaths in 2020. The most common in 2020 (in terms of new cases of cancer) are: breast (2.26 million cases); lung (2.21 million cases); colon and rectum (1.93 million cases); prostate (1.41 million cases); skin (non-melanoma) (1.20 million cases) and stomach (1.09 million cases) [2]. Radiotherapy is recognized as an essential element of an effective cancer care program throughout the world. It is vital component of the treatment of cancer for many years. Aproximatelly half of all cancer patients requiring a radiotherapy in some time of their deceases. Abdel-Wahab et al. [3], Barton et al. [4], and Atun et al. [5], argue, that radiotherapy is a critical and cost-effective component of a comprehensive cancer control plan [6].

Modern radiotherapy is a very complex process of treatment planning and delivery of radiation dose. Today, radiotherapy encompasses a lot of steps from clinical evaluation to posttreatment follow-up. The clinical process of modern radiation therapy starts with a therapeutic decision at the first appointment with cancer patient, where the radiation oncologist prescribes the radiotherapy treatment. Then the immobilization of patient is performed, which be adopted during treatment. A computerized tomography (CT) scan of the patient is acquired for delineations of the planning target volumes (PTV) and the organs-at-risk (OARs). The CT images may be fusion with other imaging modalities such as magnetic resonance imaging (MRI) and positron emission tomography (PET) for the precise determination of PTV and OARs. A treatment plan is created on a treatment planning system (TPS) based on the outlined structures and on the dose prescription to the PTV and

tolerance dose criteria to the OARs. A pre-treatment quality assurance (QA) verification of the treatment plan has been performed after its evaluation and approving by the radiation oncologist. Image guided radiation therapy (IGRT) modality is using to check patient positioning before each treatment.

In recent years, radiotherapy has been advancing toward achieving a higher cure rate with a higher therapeutic dose and minimum side-effects. This has been possible through the development of high-performance and highprecision radiotherapy techniques and by applying cutting-edge medical technologies [7].

Modern radiotherapy reached a very high degree of complexity and sophistication and expected to represent an added value for the cancer patients in terms of clinical outcomes and improved radiation protection.

In 2016, IAEA published a new guidance document titled: Accuracy Requirements and Uncertainties in Radiotherapy [8]. All forms of radiotherapy should be applied as accurately as reasonably achievable with technical and biological factors being considered, but that regular independent dosimetry audit be conducted using postal (remote) or on-site visits [9].

3. History of dosimetry audit

The concept of verifying the realized dose in the medical applications of ionizing radiation was introduced in the early 20th century shortly after the first application of X-rays for the treatment of cancer.

Initially, in order to adequately assess the daily fraction that would be prescribed to patients, doctors irradiated their own hands to observe a skin reaction - "dose of erythema".

In 1925, the Swedish physicist R. Sievert [10] created a circulating physical department to standardize the Roentgen radiation (X-rays) used in oncology therapy in his country. The department found some unreliable dosimeters and identified the need for better protective equipment for X-ray personnel. At the same time, the data collected from the measurements of the dosimetric value - Percent Depth Dose (PDD) were used as reference values for the technical equipment used for clinical purposes at that time.

Another documented example of an early dosimetry audit was found in Poland, following Marie Curie's idea that a Laboratory for measuring the dose of X-rays and the radioactive isotope radium used in hospitals at the time should be opened. The laboratory for dosimetry measurements was founded in 1936 [10].

The dosimety laboratory in the International Atomic Energy Agency (IAEA) was established in the early 1960s to organize and conduct dosimetry audits for radiotherapy centers worldwide and to ensure international consistency in radiation dosimetry. The first pilot postal comparison of the radiation dose between different radiotherapy centers was organized by the IAEA in the period 1965–1966 as a joint project with the World Health Organization (WHO).

4. The essence of dosimetry audit

Dosimetry audit (DA) is a tool for quality improvement. It can be defined as a systematic and critical analysis of the quality of the dosimetry activities performed in specific radiotherapy center. The dosimetry audit includes an assessment of data, documents and resources in order to verify the performed clinical dosimetry activity against the adopted international standards of good practice. The essence of the dosimetry audit can be summarized as:

- Improving the quality and organization of the dosimetry activities.
- Further professional training of medical physicists.
- Increasing the efficiency and safety of the radiotherapy.
- Improving the quality of the overall radiotherapy process.
- Promoting the efficient use of available resources.

The results of the dosimetry audit inform the staff about the main elements of the quality and the weaknesses of the dosimetry activities carried out, comparing the audited dosimetric practice with the standards for good clinical radiation dosimetry. Dosimetry audit identify areas for improvement and provide confidence in safety and efficacy, which are essential to creating a clinical environment of continuous development and improvement.

One of the main risks for patients undergoing radiation therapy is the delivery of a dosimetry inaccurate therapeutic dose during radiation therapy sessions. Dosimetry inaccuracies directly reflect on tumor control, cancer treatment and toxicity affected the survival, and quality of life of cancer patients. The differences between the prescribed and delivered dose directly affect the clinical outcomes. The precision of the therapeutic method of radiation therapy is mainly related to the high degree of accuracy of the radiation dose applied during the treatment of patients.

Dosimetry audit is a partial audit and related to the quality assurance procedures in the field of the performed dosimetry activities in a specific radiotherapy center and namely [11–13]:

- Quality tool that improves the accuracy of clinical radistion dosimetry.
- Conducted on a voluntary basis, but each radiotherapy center must initiate it itself.
- DA is a “second opinion”, regardless of the specific treatment center regarding the performed clinical dosimetry - procedures, protocols, measuring instruments, etc.
- Identifies gaps in procedures and methods used as well as errors in routine practice.
- Identifying and understanding of errors leads to improved quality in general in the clinical activities of specific radiotherapy center.
- Illustrates the good dosimetry practice in the field of radiation clinical dosimetry based on world standards.
- Contributes to the avoidance of accidents and omissions in the daily radiotherapy activity.
- DA is confidential.
- DA leads to the exchange of knowledge, skills, information and competence.

Dosimetry audit is proactive, ie. consists in reviewing the current clinical dosimetry in order to improve its quality. It is organized and conducted remotely, ie. It is (remote audit).

Dosimetry audit worldwide are organized in different ways, often for geographical, economic or political reasons, but mainly check the fundamental value - the absorbed dose in reference conditions, ie. so-called - beam output [12]. The measurement of the value of the absorbed dose in the so-called reference conditions i.e. beam output is the most fundamental measurement that confirms whether the therapeutic system generating ionizing radiation and used for radiotherapy is properly calibrated [14].

The existence of an error in the calibration of the radiation beams leads to the creation of a systemic error in the treatment of each individual patient, which in turn leads to systemic differences in the results of the conducted radiation therapy.

DA is a key component in quality management in radiotherapy and plays an important role in the safe application and use of new methods and techniques of radiotherapy [15, 16].

5. Types of dosimetry audit

The International Atomic Energy Agency (IAEA) as the founder of the idea of dosimetry audit and main organizator of the program for postal dosimetryc audit with thermoluminescent dosimeters (TLDs) and radiophotoluminescent dosimeters (RPLDs) for nearly fifty years has identified the following types [17] (See **Figure 1**).

Level	Tasks	Dosimetry equipment	Phantom
Level 1	Verification of the photon and electron beam output under reference conditions	**R**(1): TLD, OSLD, RPLD Alanine **O**(1): Ion chamber, 2D & 3D Array, TLD, OSLD, RPLD, Alanine	Water Geometric/solid
Level 2	Verification of the photon and electron beam relative dosimetry parameters under non-reference conditions on- and off-central axis	**R**: TLD, OSLD, RPLD, Alanine, films, diodes **O**: Ion chamber, 2D & 3D Array, films, diodes, TLD, OSLD, RPLD, Alanine	Water Geometric/solid
Level 3	Verification of complex dosimetry parameters using geometric / rectilinear phantom or anthropomorphic phantom. Treatment planning system (TPS) dose calculations are compared to audit measurements.	**R**: TLD, OSLD, RPLD Alanine, films, diodes, 2D & 3D Array **O**: Ion chamber, 2D & 3D Array, films, diodes, TLD, OSLD, RPLD, Alanine	Water Geometric/solid Anthropomorphic
Level 4	Verification of advanced treatment modalities, e.g. IMRT, VMAT, SRS, SRT, using an end-to-end anthropomorphic phantom that approximates a patient treatment, including targets, organs at risk and heterogeneities.	**R**: TLD, OSLD, RPLD, Alanine, films, diodes, 3D dosimeters (e.g. polymer, PRESAGE, Fricke gels) **O**: Ion chamber, 2D & 3D Array, films, diodes, TLD, OSLD, RPLD, Alanine, 3D dosimeters (e.g. polymer, PRESAGE, Fricke gels)	Anthropomorphic

(1) **R**: Remote audits, **O**: On-site audits

Figure 1.
IAEA classification of different types dosimetry audits [17].

6. Current status of dosimetry audit in the member countries of the european federation of organizations for medical physics (EFOMP)

The European Union has issued a new directive on the use of ionizing radiation for medical purposes 2013/58 / EURATOM, which entered into force in 2014 [18]. The new Directive updates the basic standards for radiation protection in clinical and professional settings, emphasizes clinical audits, reinforces their importance for quality improvement and recommends, that Member States ensure that dosimetry audits are carried out in accordance with national audit procedures.

A clinical audit is defined as "a systematic review or review of medical radiological procedures that seeks to improve the quality and outcome of patient care through a structured review in which medical radiological practices, procedures and outcomes are performed against established standards for good medical radiological procedures. procedures, changing practices where appropriate and applying new standards if necessary."

Dosimetry audits are one of the main measures introduced to ensure the safety of patients undergoing radiotherapy. The international organizations conducting clinical trials set as a condition for participation the results of the dosimeter audit in order to evaluate the clinical dosimetry in the specific radiotherapy center, with it participated in the clinical trial [19]. In this way, dosimetry quality assurance (QA) and quality control (QC) are doubled as a tool in the fine-tuning used in clinical trial technology [20].

Performing an external dosimetry audit is an expensive procedure that requires special knowledge, skills, actions, time and effort. In some countries, basic safety standards require regular dosimetric audits with different requirements and frequencies.

The audit documentation of radiotherapy centers participating in an international clinical trial is not always easy to obtain and analyze because it is heterogeneous in terms of the type and frequency of dosimetric audit and is different for different centers and countries in Europe.

All this is the basis of the European Federation of Organizations for Medical Physics (EFOMP) to initiate a survey to determine what kind of audit, clinical or dosimetric, is required by law in different European countries, what role the medical physicist plays and to get a general idea for the regulations and practices regarding the quality assurance and quality control of the radiotherapy equipment.

EFOMP is developing a questionnaire in order to obtain the necessary information on the general requirements and standards for organizing and conducting dosimetric audit, quality assurance of dosimetric activity and periodic dosimetric inspections in EU countries at the end of 2019. The questions are addressed to the community of medical physicists to assess the regulatory status of dosimetric audits performed in radiotherapy centers.

The questionnaire was sent to 33 National Member Organizations (NMOs) in November 2019 (at the time of the survey's dissemination, 33 NMOs were part of EFOMP). The results were obtained in the period December 2019–March 2020.

The first section of the questionnaire refers to the requirements for conducting periodic dosimetric audits in radiotherapy centers in Europe, the subject (auditor) performing the audit according to national legislation, as well as the source of the auditor (internal / external).

19 NMOs (58%) of the 33 EFOM members replied to the questionnaire. Of these, 14 are EU Member States (54%) and 5 are non-EU (46%).

In eleven European countries (11/19 NMOs), 9 EU members and 2 non-EU countries, national regulations require regular dosimetric audits to be carried out in radiotherapy centers (See **Figure 2**).

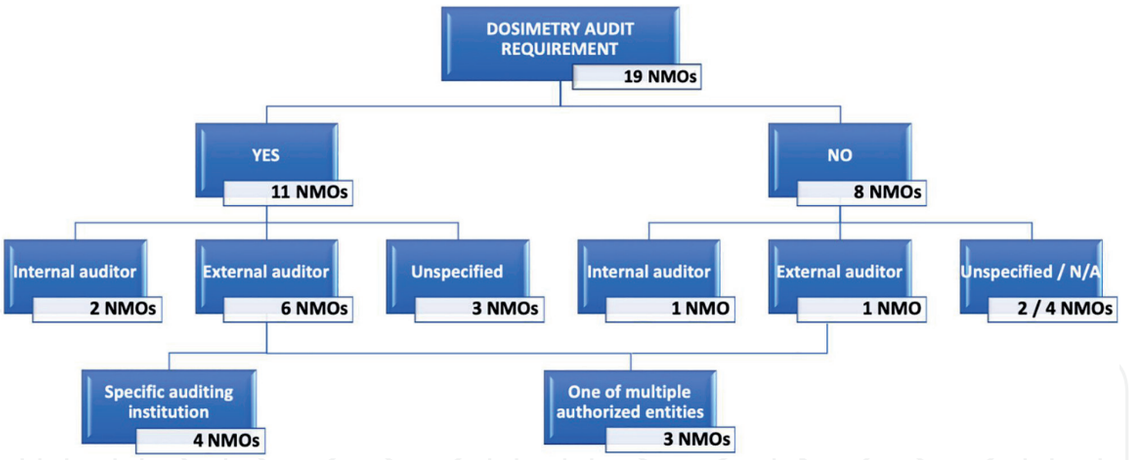

Figure 2.
Dosimetric audit requirements according to the NMO responses [20].

Dosimetry audits are performed as follows: by external auditors in (6/11 NMOs), by internal auditors (2/11 NMOs) and by an unspecified auditor in (3/11 NMOs). 42% (8/19 NMOs), of which 5 EU members and 3 non-EU countries state that the requirements for conducting a dosimetric audit are not regulated at national level.

Only 11 NMOs report that national regulations require regular dosimetric audits of radiotherapy centers, but only 6 European countries state that there are well-established procedures that must be followed for an audit to be valid. Dosimetric audit is of great interest to EFOMP and is given great importance in Council Directive 2013/59 / EURATOM. Overall, the EFOMP study shows significant heterogeneity in national policies on the dosimetric audit program of radiotherapy centers.

Dosimetric audits were conducted in only 58% of the countries (NMOs) that participated in the survey organized and conducted by EFOMP in November 2019, although the deadline for transposition of the European Directive 2013/59 / EURATOM into national legislations is the end of 2019.

7. Radiophotoluminescent dosimeters (RPLDs)

The physical phenomenon of photoluminescence is the basis for the detection of ionizing radiation with radiophotoluminescent dosimeters. Radiophotoluminescence as a phenomenon shows that some materials, after irradiation with sources of ionizing radiation, begin to luminesce under illumination with ultraviolet (UV) light and the luminescent light is proportional to the dose they were irradiated [21] (See **Figures 3** and **4**).

This effect was used to create radiophotoluminescent (RFL) dosimeters, which are alumina-phosphate glasses, activated with silver and synthesized by a special technology that used the effect of photoluminescence.

In 1949, the RPL phenomenon was first discovered and applied for measuring the dose in the event of a radiation accident. The magnitude of the radiation dose ranged from 0.1 to 1 Gy [22]. At that time, there were still some problems with glass surface contamination and measuring the RPL signal became a technical challenge. Later, the ability to register ionizing radiation was drastically improved by changing the chemical composition of the glass used. Thus, the measurement range is from 0.1 mGy to 10 Gy [23].

Radiophotoluminescent dosimeters are an accumulative type of dosimeter. They work on the principle of the phenomenon of radiophotoluminescence, which is

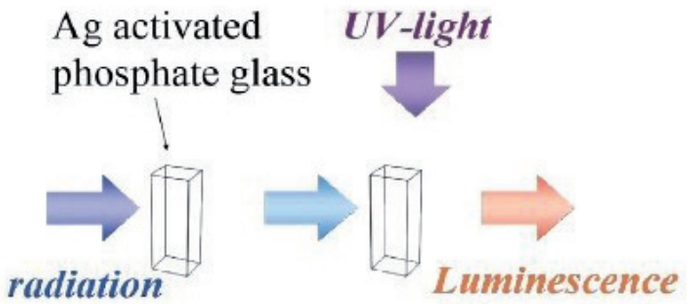

Figure 3.
Schematic representation of the RPL process in phosphate glass doped with silver Ag+ ions [21].

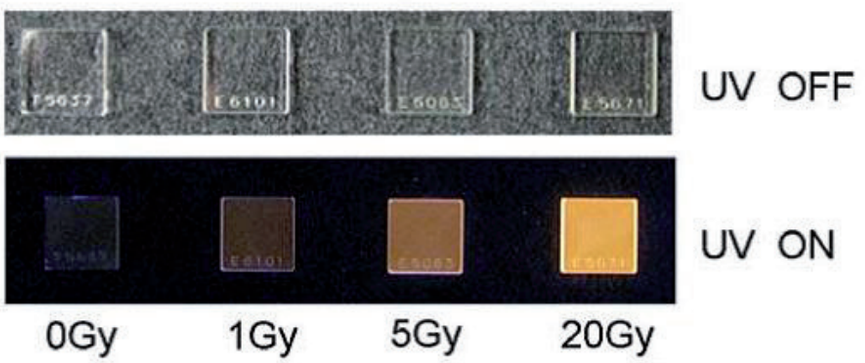

Figure 4.
The amount of luminescent light is proportional to the radiation dose [21].

observed in some solids. RPLDs are made of silver-activated phosphate glass and are shaped like small glass rods (See **Figure 5**).

The glass rods are 12 mm long and 1.5 mm in diameter. Each glass rod has an identification number engraved on one end. The sensitive area of the dosimeter is 6 mm long. When irradiated with ionizing radiation, stable luminescent centers are formed in the silver ions - positive and negative. The measurement of the absorbed dose is performed by optical excitation of the dosimeter with a laser emitting ultraviolet light [21]. The first RPLD was produced in 1949 [22]. Significant technological improvements have been made over time, including the accuracy and reliability of their measurement [23]. They are currently one of the best solid state dosimeters [21].

Figure 5.
General type of radiophotoluminescent dosimeters (RPLDs) – glass rods.

Today, the production of RPL dosimetry is advancing remarkably thanks to modern electronics and is well accepted as a solid-state, passive dosimeter operating in the range of 10μGy to 10 Gy, using a pulsed laser beam of UV light. Radiophotoluminescence dosimeters (RPLD) as a new type of solid state dosimeters are used in radiation dosimetry for radiotherapy in the last two decades.

8. Dosimety audit with radiophotoluminescent dosimeters (RPLDs) in reference conditions

The dosimetry system based on radiophotoluminescent dosimeters (RPLDs) is the Ace Dosimetry System, consisting of GD-302 M glass rods and an FDG-1000 reader from Asahi Techno Glass Corporation (ATG). It is used in IAEA Dosimetry Laboaratory (See **Figure 6**).

The glass rods are made of silver-activated phosphate glass. They are 12 mm long and 1.5 mm in diameter. Each glass rod has an identification number engraved on one end. The sensitive area of the dosimeter is 6 mm long. The glass rods are placed in specially made waterproof capsules. Each capsule with a glass rod already placed in it can be considered as an *RPLD Dosimeter* (See **Figure 7**). The capsules, model M5001 produced by MISATO Precision Inc., is made of high density polyethylene (HDPE, Nipolon Hard 2000, Tosoh Corporation, Japan). It consists of a container with approximate cylindrical symmetry and with an internal 12.1-mm-long cylindrical cavity of 1.8 mm of diameter [24].

The dosimetry audit with RPLDs is the newest form of the audit offering as a service by IAEA Dosimetry Laboratory to the Member States. The participants

Figure 6.
Dose Ace dosimetry system consisting of GD-302 M glass rods and an FGD-1000 reader/analyzer from the Japanese Asahi Techno Glass Corporation (ATG).

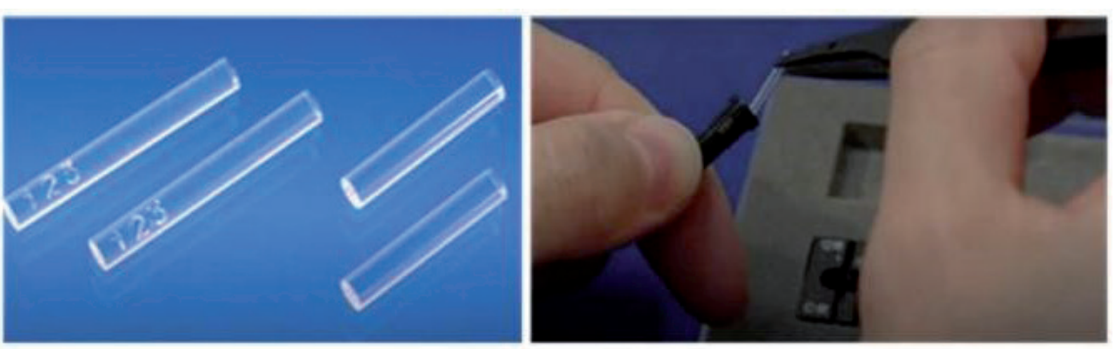

Figure 7.
Glass rods on the left and waterproof capsule on the right.

(radiotherapy centers) should to irradiate the RPLDs in a water phantom using an IAEA standard holder in reference conditions: S = 10x10 cm field size, 10 cm depth in water phantom and nominal Source Surface Distance (SSD) or Source Axis Distance (SAD) of 100 cm used clinically.

Each capsule has an ID number and a bar code. The sensitive area is also marked on the capsule to allow precise positioning (See **Figure 8**).

The purpose of the dosimetric audit is to perform the measurements specified in the instruction in the same conditions under which the patients are irradiated on daily basis (See **Figure 9**).

The irradiation procedure of RPLDs includes the following steps according to the IAEA instruction sheet [25, 26]:

I. Preparation of beam, phantom and hoder for irradiation of RPLDs.

1. Assemble the holder (**Figure 10**).

2. Place the holder in a water tank on the treatment table (**Figure 11**).

3. Set the therapy unit for a vertical beam, with a 10 cm x 10 cm field size (**Figure 11**).

4. Align the holder tube with the central axis of the beam (**Figure 11**).

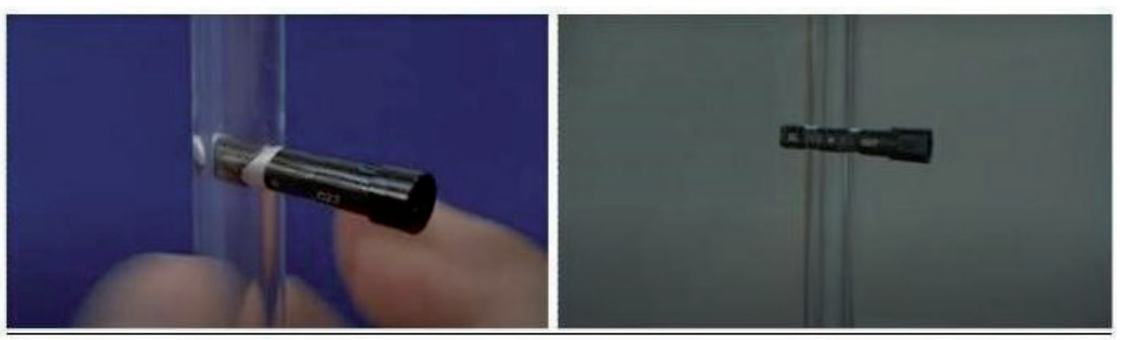

Figure 8.
ID number and bar code of the capsules – in the left. The sensitive area is marked on the capsule – in the right.

Figure 9.
The dosimetry audit should be performed in the same conditions in which patient is irradiated during treatment procedure.

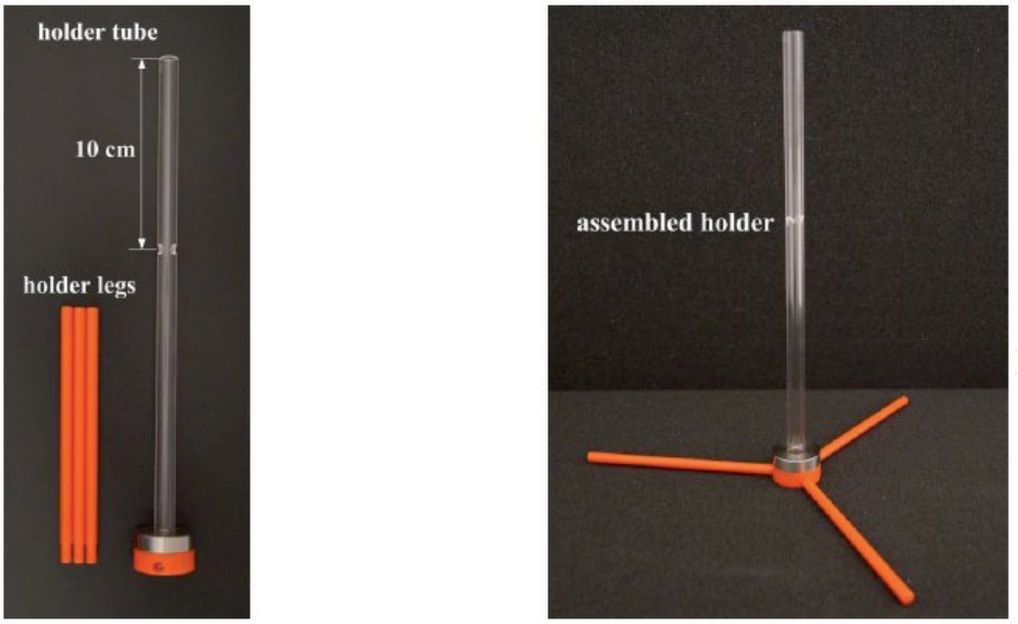

Figure 10.
Assembling the IAEA standard holder for the RPLDs irradiations [25, 26].

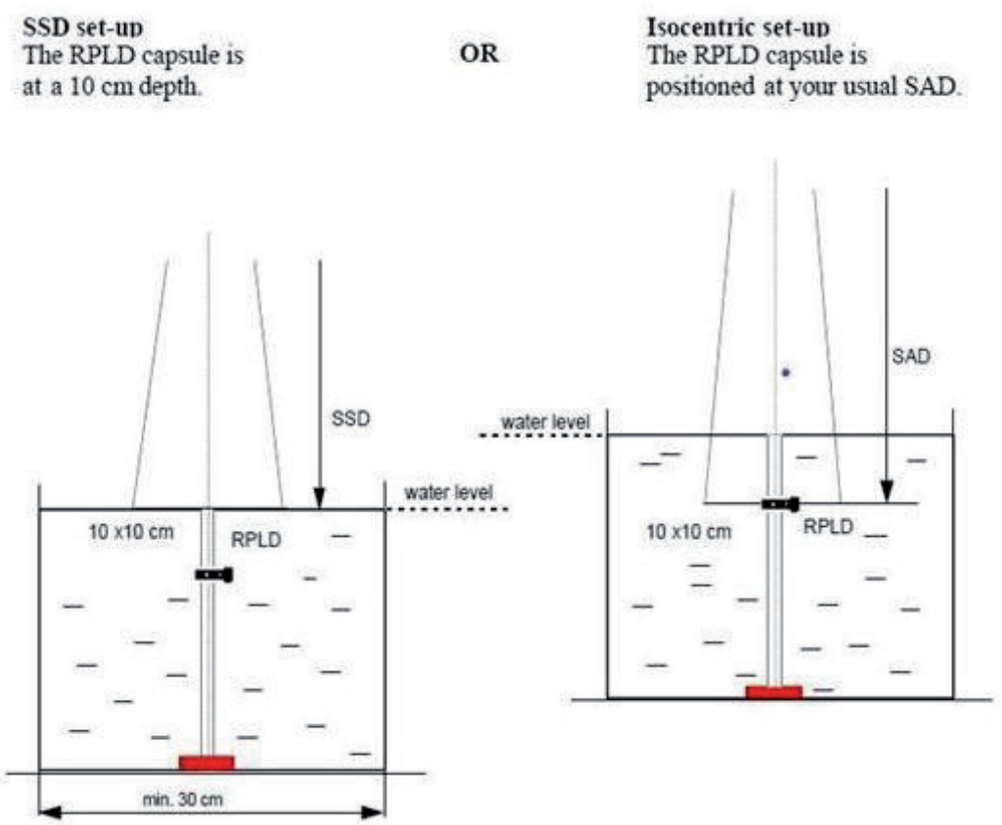

Figure 11.
Two alternative geometry set-ups for the RPLD irradiation [25, 26].

5. Adjust the water level by filling the water tank exactly to the level of the top of the holder. Make sure that the tube of the holder is also filled with water (**Figure 11**).

6. Adjust the patient' couch height so that the water surface is at your usual distance using in the daily clinical practice.

II. Irradiation of the RPLDs.

The procedure of irradiation of the dosimeters covers the following actions:

1. Before irradiation recheck whether the alignment, field size, water level and distance are correct (**Figure 11**).

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 12**).

3. Irradiate the RPLD capsule with the number of monitor units (MU) calculated above.

4. Remove the capsule from the holder (**Figure 12**) and wipe it dry.

5. Repeat the procedure, steps 2 to 4, for the second capsule.

The total 2 /two/ RPLD capsules per beam should be irradiated for the purpose of dosimetry audit.

The following recommendations should be taken into account:

1. An RPLD capsule in a small bag must not be irradiated, because it is used to record environmental influences during transport and storage.

2. Calculation of the number of monitor units to deliver 2 Gy to a tumor, 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 RPLD reader according to the expression:

$$D = M.N.SCF.PCF.f_{lin}.f_{fad}.f_{en}.f_{hol}, \quad (1)$$

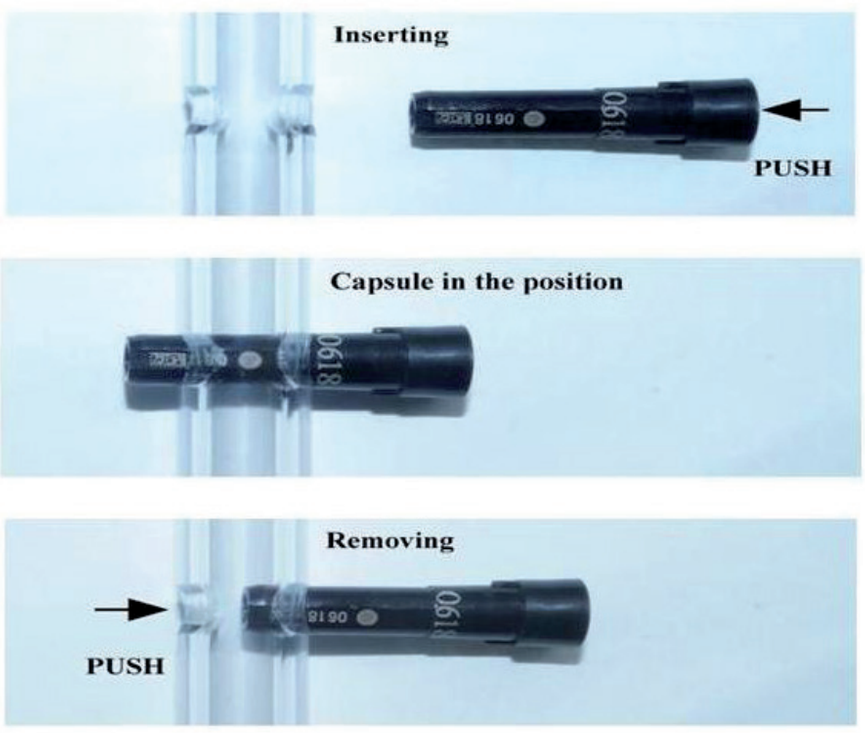

Figure 12.
Different positions of the capsule with RPLD – inserting, capsule in the position and removing [25, 26].

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.

$\mathbf{f_{lin}}$ – is the non-linearity dose response correction factor.

$\mathbf{f_{en}}$ - is the energy correction factor.

$\mathbf{f_{fad}}$ – is the fading correction factor.

$\mathbf{f_{hol}}$ – is the standard IAEA RPLD holder correction factor.

The determination of all these factors, their values, meitanence, quality assurance and combined uncertainty of the RPLD system are comprehensively given in [27].

9. Results of dosimetry audit with RPLDs

Bulgarian radiotherapy centres participated in the IAEA/WHO Postal Dose Audit Service with (RPLD) in last three years. The new Varian and Elekta therapy treatment machines have been installed in 2011–2017. The energy of the photon beams is in the range of 6 MV-15 MV. The total number of 34 beams were cheked. The results are given on **Figure 13**. The 33 beams (97%) in reference conditions are in the tolerance of +/− 5%. Follow up have been organized for the beam exceed the tolerance and successfully is clarified the reason. The results of the dosimetry audits despite the fact, that the radiotherapy equipment in Bulgaria was in long-term technology stagnation, show the ability of Bulgarian medical physicists to provide quality dosimetric control at the current world criteria.

The results 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

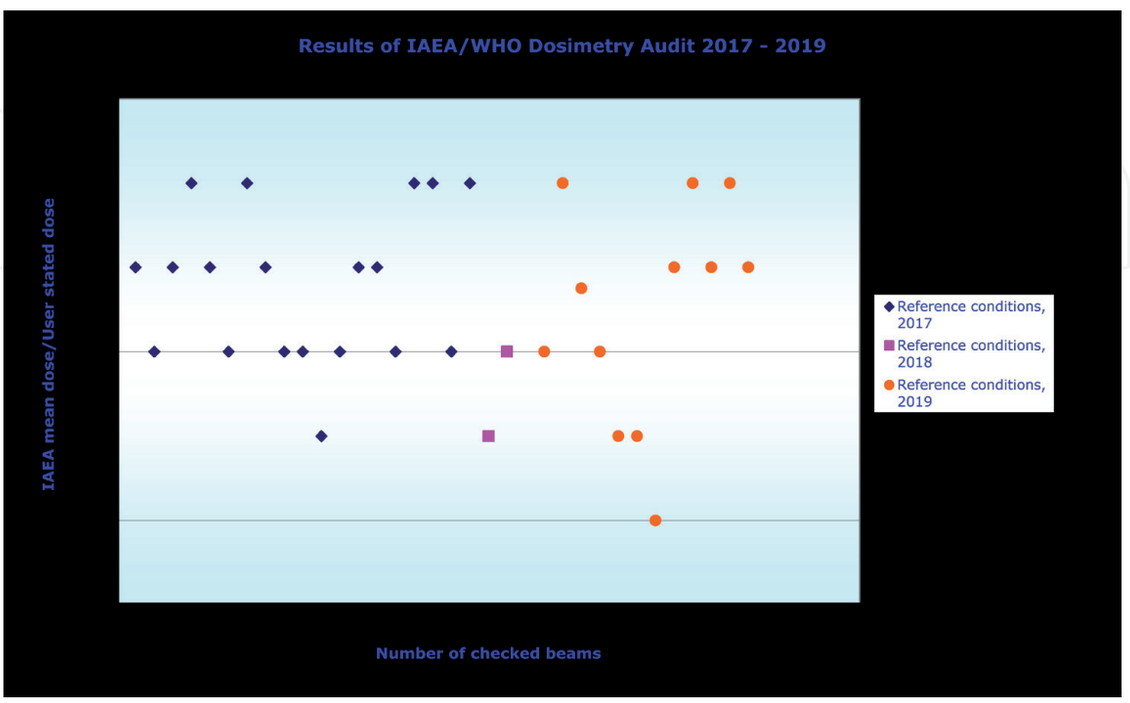

Figure 13.
The results of IAEA/WHO RPLD audit 2017–2019. Ratios of IAEA mean dose/stated dose. Each point in the graph represent averaged dose of 2(two) capsules.

knowledge, experience and skills of the staff of medical physicists due to their regularly participation in the dosimetry audits.

Independent dosimetry audits play an important role in patient treatment quality, radiation protection and safety. Audits have the potential to identify issues and resolve them, reducing the probability of harmful errors to occur. They also support the safe implementation of new techniques and technologies, and promote knowledge sharing at a national and/or international level by benchmarking centres with similar equipment [28]. Indeed, the IAEA stresses the importance of every radiotherapy centre equipped with new machines and those that are going to introduce new treatment techniques in clinical practice, participate in dosimetry audits before starting treating patients, and regularly after that [29]. Moreover, a recent European Directive (2013/59 Euratom) recommends that new radiological procedures should be audited. Independent dose audits are also mandatory in many multi-institutional clinical trials in radiotherapy to ensure that participants deliver accurate doses and so the reported results are not biased [30–32].

10. Discussion

The need of safe and effective radiotherapy is growing as cancer morbidity is growing worldwide. Modern radiotherapy is used to treat and improve the quality of life of patients undergoing this type of therapy. Currently, radiation therapy is widely recognized as one of the safest areas of modern medicine and errors in radiation therapy are very rare [33].

Patient safety is of paramount importance to medical staff in radiotherapy centers and safety considerations are an element in all aspects of the day-to-day clinical activities. Technological advances and clinical research over the past few decades have given radiation oncologists the capability to personalize treatments for accurate delivery of radiation dose based on clinical parameters and anatomical information. Two major strategies, acting synergistically, will enable further widening of the therapeutic window of radiation oncology in the era of precision medicine: technology-driven improvement of treatment conformity, including advanced image guidance and particle therapy, and novel biological concepts for personalized treatment, including biomarker-guided prescription, combined treatment modalities and adaptation of treatment during its course [34].

Modern radiotherapy is one of most rapidly developing nuclear applications in medicine and today it is a safe and highly effective cancer treatment modality. Precise radiation dosimetry measurements are used to keep radiotherapy safe and effective. The need of dosimetric and geometric accuracy in radiotherapy is well defined [28, 35]. 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 [36].

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. 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. The total results of 13,756 individual TLD/RPLD irradiated sets over a period of 50 years were readout, evaluated and analyzed. 86% of them are within the 5% acceptance limit [37].

11. Conclusion

In our days, modern radiation therapy requires technologically advanced equipment and a professional strategy for the treatment of cancer patients in order to achieve the best clinical result, especially when the vision of the European Society for Radiation Therapy and Oncology for 2020 is: "Every cancer patient in Europe will have access to state-of-the-art radiation therapy as part of a multidisciplinary approach in which treatment is individualized for a particular patient's cancer, taking into account the patient's personal circumstances" [38].

Professionalism and morality oblige us to provide safe and effective radiation therapy, i.e. to know, that we are doing everything well, but also to be able to do it even better. Times have changed, mostly for the better. Few could argue with the fact that the tools we work with today are extremely superior and extremely complex than a few years ago. Advances in technology provide more sophisticated, promising and accurate techniques for targeting malignancies, while minimizing normal tissue damage is crucial for patients treated with radiation therapy [39].

Dosimetry audit has been identified in the activities of ESTRO as one of the most important topics, accompanying the improvement of the quality of radiotherapy practice in Europe through standardization [28]. International organizations as the IAEA and EU in their recent recommendations place external dosimetry audit as a mandatory element in the quality assurance program in radiotherapy [18, 35].

Over the years, the audits have contributed to good dosimetry practice and accuracy of dose measurements in modern radiotherapy. Dosimetry audit ensures, that the correct therapeutic dose is delivered to the patients undergoing radiotherapy and play a key role in activities to create a good *radiation protection* and *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 newest technologies undoubtedly lead to constant trends in the enhancing of the basic principles of *radiation protection* - justification and optimization and to create a good safety culture allowing us to treat more cancer patients in efficient, effective and safely manner.

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Conflict of interest

The author declare no conflict of interest.

Notes

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