CAPABILITIES OF ELECTRET ION CHAMBERS TO MEASURE ABSORBED DOSE OUTSIDE THE TREATED VOLUME, DURING EXTERNAL-PHOTON RADIATION THERAPY

by

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The capabilities of electret ion chambers to measure non-target absorbed dose during radiotherapy treatment was investigated for the first time. During radiotherapy, non-target doses can be classified as one of three approximate dose levels: high doses, intermediate doses and low doses. Low doses (<5 % of the prescription dose) are not generally considered during treatment planning, due to the fact that is difficult to measure, characterize, or model them in the planning system. In this work were performed measurements with electret ion chambers of absorbed dose outside the treated volume (<5 % of the prescription dose), during external photon radiation therapy in an Elekta Infinity Linear Accelerator of *Theagenio* Cancer Hospital of Thessaloniki, Greece. The absorbed dose values for distances 8-100 cm from the borders of the irradiated volume varied from 0.3 to 17 mGy which corresponds to 0.01 % up to 0.6 % of the prescription dose (2660 mGy). Near the irradiation volume the absorbed dose values were greater than the upper detection limit of the electret ion chambers (threshold 40 mGy). The results are compared with the calculated ones by the Monaco treatment planning system – TPS (Elekta Monaco at November 5, 2003) in three positions distanced at 8 cm and about 30 cm from the border of the irradiation zone. In the position at 8 cm from the irradiation zone, where Monaco TPS calculates (within uncertainty of about 15 %) the absorbed dose, measured and calculated doses are the same within experimental uncertainties. On the contrary for the other two positions, where leakage radiation becomes the dominant source of out-of-field dose the absorbed dose values calculated by the TPS are seriously underestimated (by a factor of 4) due to the fact that TPS does not take into account the leakage radiation. However, adding to the TPS values an estimated dose due to leakage radiation, the difference between measured and calculated doses are about 30 %.

Key words: electret ion chamber, radiation therapy, absorbed dose

INTRODUCTION

Electret ion chambers (EIC) are passive charge-integrating devices for accurate measurement of different type of radiations [1-6]. They are inexpensive, lightweight, commercially available and are mainly used for short- or long-term radon measurements. The use of EIC as gamma dosimeter is uncommon in comparison to thermoluminescent dosimeter (TLD) which is used in most of the environmental gamma monitoring and medical applications. The main scope of this work is to investigate the capabilities of EIC to measure the absorbed dose, for radiation protection purposes, outside the treated volume, during external photon radiation therapy.

During radiotherapy, non-target dose can be classified [7] as one of three approximate dose levels. High doses (>50 % of the prescription dose) are typically directly optimized during the planning process. Intermediate doses (5-50 % of the prescription dose) are also often addressed during optimization but are not generally the focus of the treatment plan. Low doses (<5 % of the prescription dose) are not generally considered during treatment planning, since is difficult to measure, characterize, or model them in the planning system. Out of field dosimetry in radiotherapy becomes more important recently since survival rate after radiotherapy has been prolonged significantly. The TPS used in radiotherapy are not adequate for handling out-of-field dose calculations [8]. It is the scope of this work to measure the absorbed dose with EIC in the low doses (<5 % of the prescription dose) regions, during external-photon radiation therapy with

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a 6 MV beam in the Linear Accelerator (Elekta LINAC) of the *Theagenio* Cancer Hospital of Thessaloniki, Greece and compare the results to calculated ones by Monaco Treatment Planning System (Elekta Monaco at November 5, 2003) [9].

MATERIALS AND METHODS

The EIC consists of a conducting plastic chamber containing an electret, fig.1, and as mentioned in the Introduction is mainly used for short- or long-term radon measurements. Radon gas passively diffuses into the chamber through filtered inlets, and the alpha particles emitted by the decay process of radon ionize air molecules. Ions produced inside the chamber's volume are collected onto the surface of the electret, causing a reduction of its surface charge. The electret voltage decreases proportional to the integrated radon concentration. A voltage reader is used to measure the electret's surface voltage. Using appropriate calibration factors and the exposure time, the mean radon concentration can be calculated. However, with small modifications EIC can be used for other type of radiation measurements. Particularly, EIC can become gamma monitors when sealed in a radon leak tight enclosure. In this case the ionization of air molecules is due to the interaction of gamma radiation with the material of EIC and not due to the decay process of radon.

Electret types of ion chambers make use of the drop of surface voltage on a dielectric material, usually Teflon, which is quasi-permanently charged. The electret has the shape of a disk about 0.13-1.5 mm thick and 34 mm in diameter. Electrets are prepared by being heated and simultaneously exposed to an electric field. Due to this process, many dipoles in the material become oriented in a preferred direction. After the heating, the material is *frozen* and can keep the position of its electric dipoles for a long period of time. A voltage gradient of several hundred volts can be maintained between the surfaces of the electret disk. One surface of the electret is kept in contact with the wall of an ion chamber, which builds up an electric field in the

Figure 1. The EIC containing a chamber (53 cm^3) and an electret

chamber. Ionizing radiation causes a decrease of charge in that system, resulting in a partial neutralization of the charge at the electret. Measurement of the electret voltage difference before and after irradiation allows determination of the amount of ionization.

The EIC are supplied by Rad. Elec. Inc. The most commonly used are available in six different configurations. Two different charged Teflon discs, named short term electrets with high sensitivity and long term electrets with low sensitivity are available. The first type is the Teflon electret made of PTFE Teflon (polytetrafluoroethylene) with a thickness of 1.588 mm and the second type is Teflon electret made of FEP Teflon (fluorinated ethylene propylene) with a thickness of 0.127 mm. The sensitivity of the electrets is proportional to the thickness of the electret, which means that short term electrets are 12.5 times more sensitive than long term electrets when same type of chambers are used. The short and long term electrets can be associated with three different chambers named L (53 cm^3), S (210 cm^3), and H (960 cm^3). In this work the LST configuration (short term electret associated with L chamber) and LLT (long term electret associated with L chamber) were used.

The EIC were calibrated in terms of absorbed dose in the Ionizing Radiation Calibration Laboratory (IRCL) of the Greek Atomic Energy Commission (EEAE). The EEAE Ionizing Radiation Calibration Laboratory is a secondary standard calibration laboratory which has developed and maintains the national standards of Gy, Sv, C kg^{-1} for gamma, X and beta radiation in Greece. The calibrations are performed in terms of air kerma, absorbed dose, personal dose equivalent at depth 10 and 0.07 mm Hp(10) and Hp(0,07), Ambient Dose Equivalent at depth 10 mm, H*(10), and Exposure in the fields of radiotherapy, diagnostic radiology and mammography, as well as in radiation protection and individual monitoring.

The EIC were irradiated at different photon energies (from 83 keV up to 1332 keV) at 0° incidence (irradiation field perpendicular to the electret surface). The absorbed dose values were selected to obtain a voltage drop of about 40-60 V, after which the voltage drop was measured. For each photon energy three to five new, unused, EIC were used. Calibration factors (electret's volt age drop due to irradiation in terms of absorbed dose in VmGy^{-1}) were deduced as function of the incident's photon energy. In fig. 2 is shown the photon energy dependence of the calibration factors for short term and long term electrets associated to L chamber (LST and LLT configuration). Almost no energy dependence of the calibration factors is found. A mean calibration factor of 200 20 V mGy^{-1} for the short term electrets (LST configuration) is found. For long term electrets associated to L chamber (LLT configuration) the mean calibration factor is 12.5 times smaller (16 2 V mGy^{-1}). A sensitivity ratio equal to 12.5 between short and long term electrets was found also [10] by irradiations of LST and LLT configurations in the Polytechnic of Milano in Italy using a

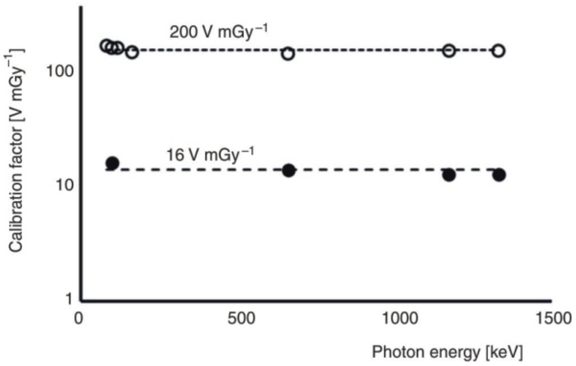

Figure 2. Energy dependence of the calibration factors for short-term electrets (open circles) and long-term electrets (close circles) associated with L chamber in V mGy^{-1}

^{137}Cs source. In a recent study [6], we have studied the angular dependence of short term electrets combined to L chamber for different irradiation energies (33 keV, 164 keV, 661.6 keV, 1173 keV, and 1332 keV). For most incident photon energies (except gamma rays from ^{60}Co source) an angular dependence of the calibration factors was observed. As an example, the normalized response of EIC to °0 incidence of gamma rays from ^{137}Cs source, varied between 1 (for °0 incidence) and 1.24 (for 180° incidence), with a mean value of 1.1. With gamma rays from ^{60}Co source, the angular dependence of the normalized response of EIC to °0 incidence was practically constant (0.96 to 1.01). The main disadvantage of the use of EIC during radiotherapy treatment is that the maximum dose that can be measured by the specific detectors is 3 mGy for short term electrets combined to L chambers and 40 mGy for long term electrets combined to L chambers. These values are order of magnitudes smaller, compared to the upper limit values measured by TLD. On the other hand, the absorbed dose measurement with EIC is easy and straightforward, with acceptable uncertainties. Caresana *et al*. [10] performed a detail uncertainty analysis of gamma radiation and radon measurements with EIC. Using the mathematical expressions presented in that work, an uncertainty of about 4-6 % of the calibration factors (drop voltage per absorbed dose) for short and long term electrets associated to L chamber can be deduced. About same uncertainties 3-6 % was found also by Fjield *et al*. [3] for short term electrets. In this work, the uncertainty of the calibration factor for zero degree incidence is estimated 10 %. It is higher than 6 % due to the fact that it includes also the (small) photon energy variation. In [3, 10] the calibration of the electrets were performed only with one photon energy (gamma rays from ^{137}Cs source). It should be noted that the calibration factors measured in this work with short and long term electrets for a specific photon energy (gamma rays from ^{137}Cs source) are in very good agreement with those measured by Caresana *et al*. [10].

Two short term electrets associated with L chambers were positioned, one inside each pocket (left and right side) of the trouser of the patient (male age 65, 183 cm height, 89 kg weigth) who had a post-mastectomy external photon radiation therapy (6 MV beam) in the Linear Accelerator (LINAC) of the *Theagenio* Cancer Hospital of Thessaloniki, Greece. This LINAC is one of the two matched accelerators (Elekta Infinity) which were donated to the hospital from March 2017 to September 2018 by Stavros Niarchos Foundation.

The external photon radiation therapy (6 MV beam) to the patient was performed for 16 days from 11/8/2020 to 1/9/2020. The dose received in each fraction was 2.66 Gy which corresponds to a total dose of 42.56 Gy. The irradiated volume (volume receiving 95 % of the prescription dose) according to the treatment planning system is 944,73 cm^3 and is shown in fig. 3. The physical dimensions of this volume are approximately: ~16 cm craniocaudal, ~23 cm axially, ~3.6 in depth.

In fig. 4 is shown the location of the irradiation zone and the position of the two detectors (short term electret associated with L chamber). The voltage of the electrets was measured just before and after each irradiation. Due to the relative high X-ray doses and the very short time of irradiation, there is no need to seal the detectors in a radon leak tight enclosure. In total

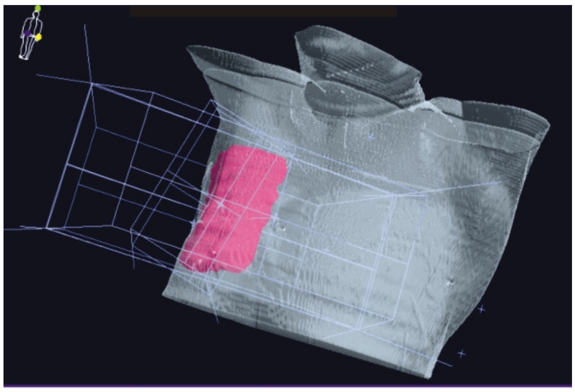

Figure 3. The irradiated volume, the isocenter position, the measuring positions, and the beam arrangement as it is shown on the body (3-D) of the patient

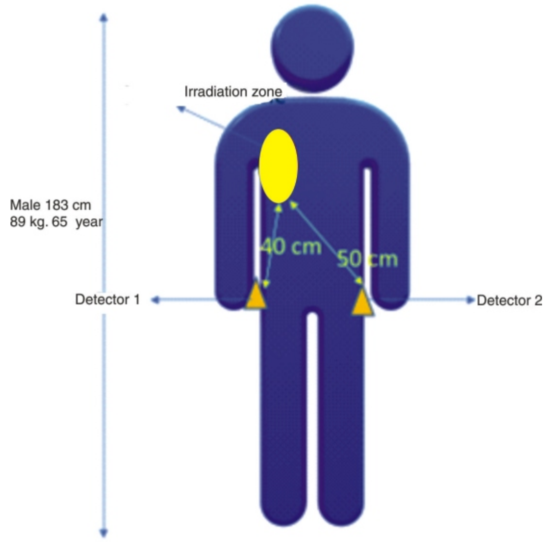

Figure 4. Irradiation zone and location of the detectors (EIC); the absorbed dose in the irradiation zone was 2.66 Gy each day for 16 days (total absorbed dose 42.56 Gy)

32 electrets were used (2 per irradiation day). From the voltage drop of the electrets due to irradiation the absorbed dose in mGy was deduced.

The 15th (31/8/2020) and 16th (1/9/2020) irradiation days, 16 short term electrets and 17 long term electrets (associated with L chambers) were positioned respectively in different positions of the patient as schematically shown in fig. 5. Again, the voltage of the electrets was measured just before and after each irradiation. The use of long term electrets, as it will be shown in the results section, turned to be necessary in order to measure absorbed dose higher than 3 mGy (upper limit of short term electrets).

In parallel to experimental measurements, Monte Carlo algorithm calculations were performed by Monaco TPS [9] (Elekta AB, Stockholm, Sweden) based on the Virtual Source Model (VSM) introduced by Sikora [11]. This model was initially created for the Elekta Precise SLI LINAC and includes three virtual sources:
- Primary photon source to model photons generated in the target.
- Secondary photon source to model photons scattered from the primary collimator, flattening filter, anti-backscatter plate and the rest of the LINAC head components.
- Electron contamination source.

All three sources are defined to have a spatial Gaussian distribution. The primary source has a fixed radial distribution, and the two other sources have energy dependent radial distributions. Particle and energy fluency for each source are derived from appropriate phase space data stored during Monte Carlo simulations. Model parameters (*e. g.*, contribution of each source, source size) are then adjusted by comparing calculated dose in water phantom against water measurements for an individual LINAC. In the Monaco beam model, the multi leaf collimator (MLC) as well as the jaws are included and modelled using transmission probability filters. Resulting particles from the model are finally used as input to the XVMC (X-ray Voxel Monte Carlo) dose calculation algorithm for dose calculations within the patient.

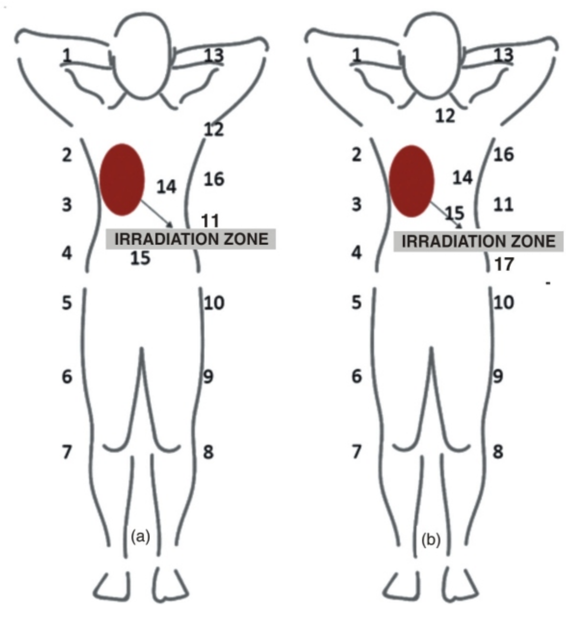

Figure 5. (a) Schematic presentation of the position of the 16 short-term electrets during the 15th (31/8/2020) irradiation day and (b) schematic presentation of the position of the 17 long-term electrets during the 16th (1/9/2020) irradiation day; the dose in the target volume (irradiation zone) is 2.66 Gy

RESULTS AND DISCUSSION

In tab. 1 are presented the results of absorbed dose values measured by the detectors positioned in two positions of the patient fig. 4 as function of the irradiation day. In the same table are presented the electrets voltage, measured just before and after each irradiation of the patient. Fifteen radiotherapy treatments were performed in the same Elekta linear accelerator (the so-called first LINAC). The radiotherapy treatment during the second (irradiation) day (12/8/2020) was performed in another Elekta linear accelerator (the so-called second LINAC) which is matched to the first one. In fig. 6 are shown the absorbed dose values measured by the detectors in the two positions of the patient (during the radiotherapy treatments with the first LINAC), as function of the irradiation day. It is clearly observed in fig. 6, that the variation (as function of the irradiation day) of the absorbed dose values is relatively small. The values are clustered around a mean absorbed dose value 1.08 mGy 15 % for detector Position 1 and 0.89 mGy 8 % for detector Position 2. The absorbed dose values measured by the detectors in Position 1 are greater compared to those measured in Position 2. This should be expected due to the fact that Position 1 is closer to the target irradiation zone than Position 2, fig. 4.

In the 15th (31/8/2020) irradiation day, 16 short term electrets were positioned in different positions of the patient (as schematically shown in fig. 5(a). Again, the voltage of the electrets was measured just before and after the irradiation. In tab. 2 are presented the results of absorbed dose measured by the 16 detectors (EIC). In the same table are presented the electrets voltage, measured just before and after the irradiation of the patient. Short term electrets associated to L chamber can measure absorbed dose values up to 3 mGy. The absorbed dose values in 50 % of the positions (8/16) are greater than this threshold. For this reason, the experiment was repeated the next day (1/9/2020), which was the last day of irradiation of the patient, using long term electrets associated with L chambers instead of short term electrets. The long term electrets, as mentioned in the previous chapter, are less sensitive to gamma radiation compared to short term electrets. For gamma radia-

Table 1. Absorbed dose (AD) measured by the two detector positions (shown in fig. 4) and electrets voltage in V measured just before and after each irradiation of the patient

Date	D1 initial voltage [V]	D1 final voltage [V]	Detector 1 AD [mGy]	D2 initial voltage [V]	D2 final voltage [V]	Detector 2 AD [mGy]
11/8/2020	699	486	1.1 0.2	677	492	0.9 0.2
12/8/2020	715	568	0.7 0.2	718	591	0.6 0.2
13/8/2020	698	471	1.1 0.2	697	501	1.0 0.2
14/8/2020	701	512	0.9 0.2	701	525	0.9 0.2
17/8/2020	728	503	1.1 0.2	698	511	0.9 0.2
18/8/2020	715	Failure	–	714	554	0.8 0.2
19/8/2020	690	471	1.1 0.2	699	506	1.0 0.2
20/8/2020	706	506	1.0 0.2	712	540	0.9 0.2
21/8/2020	709	453	1.3 0.2	720	537	0.9 0.2
24/8/2020	722	561	0.8 0.2	727	557	0.9 0.2
25/8/2020	716	467	1.2 0.2	691	488	1.0 0.2
26/8/2020	690	Failure	–	715	567	0.7 0.2
27/8/2020	707	441	1.3 0.2	712	535	0.9 0.2
28/8/2020	722	564	0.8 0.2	681	500	0.9 0.2
31/8/2020	693	461	1.2 0.2	686	527	0.8 0.2
1/9/2020	683	Failure	–	708	528	0.9 0.2

Table 2. Absorbed dose values measured by the 16 detectors (short term electrets) during the 15th (31/8/2020) irradiation day; the position of the detectors is shown in fig. 5(a); short term electrets associated to L chamber can measure absorbed dose values up to 3 mGy

Position of detector	Initial voltage [V]	Final voltage [V]	AD [mGy]
1	698	<10	Greater than 3
2	690	<10	Greater than 3
3	718	<10	Greater than 3
4	708	<10	Greater than 3
5	735	510	1.1 0.2
6	691	577	0.6 0.2
7	703	633	0.4 0.1
8	694	619	0.4 0.1
9	685	566	0.6 0.2
10	654	363	1.5 0.3
11	725	<10	Greater than 3
12	717	272	2.2 0.5
13	687	223	2.3 0.5
14	680	<10	Greater than 3
15	709	<10	Greater than 3
16	604	<10	Greater than 3

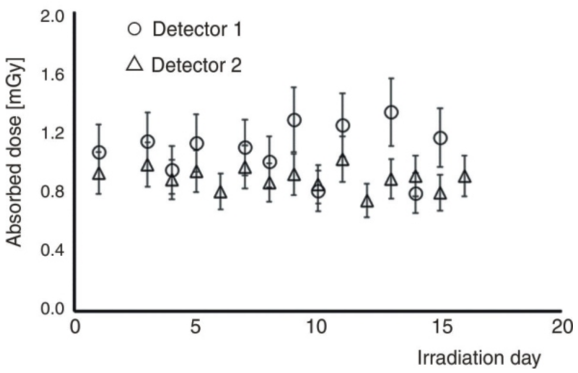

Figure 6. Absorbed dose values measured by the two detector positions during the radiotherapy treatments with the first LINAC, as a function of the irradiation day

tion, the voltage attenuation per mGy is 16 V for long term electrets compared to 200 V for short term electrets. This sensitivity disadvantage of long-term electrets compared to short term electrets has on the other way round the advantage that long term electrets can measure higher absorbed dose values up to 40 mGy. In tab. 3 are presented the results of absorbed dose measured by 17 detectors (long term electrets associated to L chambers) during the last irradiation day of the patient (1/09/2020). In the same table are presented the electrets voltage, measured just before and after the irradiation of the patient.

In fig. 7 are shown the absorbed dose values in mGy measured with short term electrets, the 15th irra-

Table 3. Absorbed dose values measured by the 17 detectors (long-term electrets) during the 16th (1/9/2020) irradiation day; the position of the detectors is shown in fig. 5(b); long-term electrets associated with the L chamber can measure absorbed dose values up to 40 mGy

Position of detector	Initial voltage [V]	Final voltage [V]	AD [mGy]
1	654	585	4.3 1
2	668	<10	Greater than 40
3	687	<10	Greater than 40
4	655	542	7.1 2
5	650	626	1.5 0.3
6	622	614	0.5 0.1
7	615	609	0.4 0.1
8	603	598	0.3 0.1
9	614	602	0.8 0.2
10	629	600	1.8 0.3
11	630	514	7.3 1.8
12	646	371	17.2 3.5
13	602	553	3.1 0.8
14	658	<10	Greater than 40
15	645	<10	Greater than 40
16	626	499	7.9 2
17	618	557	3.8 1

diation day fig. 7(a) and the absorbed dose values in mGy measured with long term electrets , the 16th irradiation day fig. 7(b), *H* means greater than the maximum dose that can be measured by the specific detectors (3 mGy for short term electrets combined to L chambers and 40 mGy for long term electrets combined to L chambers). It is clear from fig. 7 that the absorbed dose values measured (in the same positions) by the two different types of EIC (short and long term electrets) are quite similar taking also into account the uncertainties of the values shown in tab. 2 and tab. 3. For the different positions the absorbed dose values vary from 0.3 to 17 mGy which corresponds to 0.01 % up to 0.6 % of the prescription dose (2660 mGy). Studies [12] at seven Swedish clinical accelerator centres show that leakage photon radiation may give an absorbed dose contribution of up to 1 mGy for one treatment of 2000 mGy to the target volume to organs and tissues well outside the treatment volume of the patient. If scattered radiation is included this number rises to about 3 mGy. These results are in the same order to those presented in this work, fig.7.

As far as dose calculation is concerned, Monte Carlo algorithm calculation was performed by the Monaco TPS (Elekta Monaco at November 5, 2003):
- Calculation algorithm Monte Carlo (VSM) with a statistical uncertainty of 0.5 % per control point.
- The TPS (treatment planning system) does not consider the leakage radiation coming from the LINAC (Elekta Infinity, Agility head) head outside the M area which is about 0.1 % in average (less than 0.2 %). The M is the area outside the collimator (leaves and diaphragms) *field of view*,

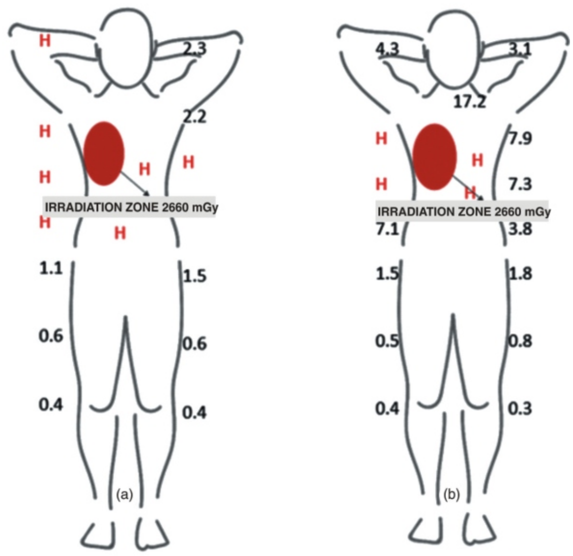

Figure 7. (a) Absorbed dose values in mGy measured with short term electrets, the 15th irradiation day, *H* means greater than 3 mGy which is the threshold for short term electrets associated with L chambers; (b) absorbed dose values in mGy measured with long term electrets, the 16th irradiation day, *H* means greater than 40 mGy which is the threshold for long term electrets associated with L chambers

where the leakage comes from LINAC components besides leaves – MLC and diaphragms (target, flattening filter *etc*). The LINAC is calibrated to have an output of 1cGy/MU for a 10X10 field size in 10 cm depth in water in a distance of 1m from the source.
- Taking into account that:

The total monitor unit (MU) of the treatment was 341,8 and the estimated treatment time given by MONACO TPS was 109,6 seconds = > ~186 MU/per minute.

The irradiation technique used was tangential IMRT in dMLC mode.

The amount of leakage radiation coming from the head in the border of the M area, is calculated at approximately 3.5 1.5 mGy.
- Structures were created simulating the electrets in dimension and position in which we calculated the mean dose.

The calculated absorbed dose (in mGy) was performed (due to the lack of CT data) only for the positions 11,12, and 16 of fig. 5(b). Position 12, is distanced 8 cm of the borders of the irradiated volume and inside the M area where Monaco TPS (Elekta Monaco at November 5, 2003) rather precisely calculates the absorbed dose, within uncertainties (as stated by the algorithm less than 15 %) which are getting larger with increasing distance from the irradiated volume. Positions 11 and 16, are inside the M area but in a longer distance, approximately 30 cm from the irradiated volume near the outbound border of the M area, where the TPS calculates the absorbed dose, within uncertainties (as

Table 4. Comparison between measured and calculated doses for three detector positions (11, 12, and 16 of fig. 5(b). The total absorbed dose calculated values are the TPS calculated values by manually adding for positions 11 and 16 the calculated absorbed dose of 3.5 1.5 mGy due to leakage

No	Absorbed dose measured [mGy]	Absorbed dose calculated by TPS [mGy]	Absorbed dose TPS +leakage [mGy]
12	17.2 3.5	18.5 1.3	18.5 2.8
16	7.9 2.0	2.0 1.0	5.5 1.8
11	7.3 1.8	1.5 0.8	5.0 1.7

stated by the algorithm less than 55 %) because of the larger distance from the irradiated volume. Also, in such distance, the leakage radiation coming from the LINAC (Elekta Infinity, Agility head) head becomes the dominant component which is not taken into account by the TPS. For these positions (11 and 16) the absorbed dose due to leakage radiation coming from the head was estimated at approximately 3.5 1.5 mGy and is added to the absorbed dose calculated by TPS.

In tab. 4 the measured and calculated absorbed doses for three detector positions (11, 12, and 16 of fig. 5(b) are compared. The absorbed dose calculated values were deduced by Monte Carlo algorithm incorporated into the Monaco TPS by manually adding for Positions 11 and 16 the calculated absorbed dose of 3.5 1.5 mGy due to leakage.It is clear from tab. 4 that in Position 12, where Monaco TPS calculates (within uncertainty of about 15 %) the absorbed dose, measured and calculated doses are the same within experimental uncertainties. On the contrary for the other two positions, where leakage radiation becomes the dominant source of out-of-field dose the absorbed dose values calculated by the TPS are seriously underestimated (by a factor of 4) due to the fact that TPS does not take into account the leakage radiation However, adding to the TPS values an estimated dose due to leakage radiation the difference between measured and calculated doses are about 30 %.

CONCLUSIONS

The capabilities of EIC to measure absorbed dose outside the treated volume during radiotherapy treatment was investigated, according to our knowledge, for the first time. This first test has some interesting results.

In most of the regions, the absorbed dose values could be measured at least with long term electrets associated with L chambers. The absorbed dose values varied from 0.3 to 17.2 mGy which corresponds to 0.01 % up to 0.6 % of the prescription dose (2660 mGy). Near the irradiation volume the absorbed dose values were greater than the upper detection limit of the EIC (threshold 40 mGy). This is a disadvantage for the use of EIC near the irradiation zone.

Using two different type of electrets (short and long term electrets) the obtained absorbed dose values (in the same positions) were quite similar a fact which gives confidence to the reliability of the results.

In the non target radiation region where Monaco TPS calculates the absorbed dose within uncertainties varying up to 15 % (Position 12), measured and calculated doses are the same within experimental uncertainties. On the contrary in Positions 11 and 16 where leakage becomes the dominant source of out-of-field dose the absorbed dose values calculated by the TPS are seriously underestimated (by a factor of 4) and assumptions of leakage contribution should be taken into account. In addition TPS accuracy on calculating the absorbed dose decreases with increasing distance from the irradiated volume (55 % for Positions 11 and 16 compared to 15 % for Position 12).

Overall, the first test of the use of EIC to measure non-target absorbed dose in distances varying from 8 cm to 100 cm from the irradiated volume during radiotherapy treatment for radiation protection purposes was positive.

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AUTHORS' CONTRIBUTIONS

Measurements were performed by all authors. Calculations by Monaco Treatment Planning System were performed by M. Chatzimarkou and A. Makridou. The manuscript was written mainly by A. Clouvas.

REFERENCES

[1] Kotrappa, P., *et al*., A Practical E-PERMTM (Electret Passive Environmental Radon Monitor) System for Indoor ^{222}Rn Measurement, *Health Phys., 58* (1990), 4, pp. 461-467

[2] Kotrappa, P., *et al*., Recent Advances in Electret Ion Chamber Technology for Radiation Measurements, *Radiat. Prot. Dosim., 47* (1993), 1-4, pp. 461-464

[3] Fjeld, R., *et al*., Field Test of Electret Ion Chambers for Environmental Monitoring, *Health Phys., 66* (1994), 2, pp. 147-154

[4] Clouvas, A., *et al*., Pilot Study of Indoor Radon in Greek Workplaces, *Radiat. Prot. Dosim., 124* (2007), 2, pp. 68-74

[5] Clouvas, A., *et al*., Indoor Radon Levels in Greek Schools, *Journal of Environmental Radioactivity, 102* (2011), 9, pp. 881-885

[6] Leontaris, F., *et al*., Procedures to Measure Mean Ambient Dose Equivalent Rates Using Electret Ion Chambers, *Radiat. Prot. Dosim., 190* (2020), 1, pp. 6-21
[7] Kry, F., *et al*., AAPM TG 158: Measurement and Calculation of Doses Outside the Treated Volume from External-Beam Radiation Therapy, *Medical Physics, 44* (2017),10, pp. 391-429
[8] Shine, N. S., *et al*., Out-of-Field Dose Calculation by a Commercial Treatment Planning System and Comparison by Monte Carlo Simulation for Varian TrueBeam®, *Journal of Medical Physics, 44* (2019), 3, pp. 156-175
[9] ***, Monaco Treatment Planning System (Elekta AB, Stockholm, Sweden) https://www.elekta. com/software-solutions/treatment-management/external-beam-planning/monaco/
[10] Caresana, M., *et al*., Uncertainties Evaluation for Electrets Based Devices Used in Radon Detection, *Radiat Prot Dosimetry, 113* (2005), 1, pp. 64-69
[11] Sikora, M., Virtual Source Modelling of Photon Beams for Monte Carlo Based Radiation Therapy Treatment Planning, Ph. D. thesis, at the University of Bergen, Bergen, Norwey, 2011
[12] Almen, A., *et al*., Leakage Photon Radiation Around Accelerators Used for Radiotherapy, *J. Radiol. Prot. 14* (1994), 4, pp. 349-357

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МОГУЋНОСТИ ЕЛЕКТРЕТ ЈОНСКИХ КОМОРА ЗА МЕРЕЊЕ АПСОРБОВАНЕ ДОЗЕ ВАН ТРЕТИРАНЕ ЗАПРЕМИНЕ, ТОКОМ ТЕРАПИЈЕ ЕКСТЕРНИМ ФОТОНСКИМ ЗРАЧЕЊЕМ

Први пут су истражене могућности електретних јонских комора за мерење апсорбоване дозе у околини мете у току третмана радиотерапијом. Током радиотерапије, дозе у околини мете могу се класификовати у три приближна нивоа: високе дозе, средње дозе и ниске дозе. Ниске дозе (<5 % прописане дозе) генерално се не узимају у обзир током планирања лечења због чињенице да их је тешко измерити, окарактерисати, или моделовати у систему планирања. У овом раду извршена су мерења са електретним јонским коморама апсорбоване дозе ван третиране запремине (<5 % прописане дозе), током терапије екстерним фотонским зрачењем у Elekta Infinity линеарном акцелератору у онколошкој болници "Theagenio" у Солуну, Грчка. Вредности апсорбоване дозе за растојања 8-100 cm од граница озраченог волумена варирале су од 0,3 mGy до 17 mGy, што одговара од 0,01 % до 0,6 % прописане дозе (2660 mGy). У близини зрачењем циљане запремине вредности апсорбоване дозе биле су веће од горње границе детекције електретних јонских комора (праг 40 mGy). Резултати су упоређени са прорачунима Монако система за планирање третмана (Electa Monaco 5.11.03) у три позиције удаљене 8 cm и око 30 cm од границе зоне озрачивања. На позицији 8 cm од зоне озрачивања, где Монако систем за планирање третмана израчунава апсорбовану дозу (унутар несигурности од око 15 %), измерене и израчунате дозе су исте у оквиру експерименталних несигурности. Напротив, за друге две позиције, где цурење зрачења постаје доминантан извор дозе изван циљаног поља, вредности апсорбоване дозе израчунате Системом планирања третмана озбиљно су потцењене (са фактором 4) због чињенице да Систем планирања третмана не узима у обзир цурење зрачења. Међутим, ако се израчунатим вредностима дода процењена доза због цурења зрачења, разлика између измерених и израчунатих доза је око 30 %.

Кључне речи: електретна јонска комора, терапија зрачењем, апсорбована доза