TECHNOLOGY INNOVATIONS

REFERENCE DETECTOR FOR SMALL FIELDS – THE T-REF CHAMBER

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Abstract— **This work takes a closer look at one of the more practical aspects of small field dosimetry: where can a reference detector be placed for profile and percentage depth dose (PDD) measurements? One possible solution to this problem is to use a large-area plane-parallel transmission chamber. In this work, such a chamber – the new T-REF chamber of PTW – is presented and analyzed. A close look is taken at the ease of use of the chamber, at the range of usable field sizes, at perturbation effects, at the signal strength and quality, and at the influence of vibrations that might be transmitted by the motors of the water phantom.**

The T-REF chamber proved to be easy to use and as long as the minimum distance of 20 cm above the water surface was respected, no perturbations were seen in PDD measurements. In profiles no deviations between different distances to the water surface and no perturbations in the out-of-field-fractions were seen. There was no influence of vibrations and the reference signal of the chamber was highly stable. Its signal to noise ratio (SNR) even exceeded that of a classical Semiflex 0.125 cm³ chamber placed in a corner of the field. To help the user in choosing the correct range of the electrometer, an examplary range-table is provided.

Keywords— **Small field dosimetry, water phantom, transmission reference detector, DAP chamber, T-REF**

I. INTRODUCTION

In dosimetry PDDs and profiles are commonly measured using a second detector obtaining a reference signal to make sure that instabilities or drifts of the linac output cannot falsify the measurements. The signal of the field detector is divided by the reference signal and the outcome is used as measurement result. The common procedure is a positioning of the reference detector in a corner of the field by mounting it on the water phantom. If the field size is big enough, e.g. 10 cm x 10 cm, the disturbance by the reference chamber does not influence the signal of the field chamber. But for field sizes below roughly 2 cm x 2 cm placing a reference detector in the field without disturbing the measurement becomes difficult. There is not enough space for placing a reference detector in, e.g., a corner of the field. The measurement would be interfered with the shadow, caused by the reference detector [12]. For solving these problems there are different possibilities.

Modern linear accelerators (linacs) usually deliver a stable signal so maybe it could be possible to measure every relative measurement without reference detector and rely on the stability of the linac output. The second possibility would be to place a standard ionisation chamber (farmer type, semi flexible etc.) nearby but outside of the field. A third technique is to take a big flat chamber and use it as transmission detector.

The disadvantages of the measurement without reference detector are that the measuring time can be a bit longer and the physicist has to rely on the stability of the linac. Many clinics do not have the newest generation of linacs or although it is new, the linac might exhibit signal drifts and need servicing. These drifts are often not noticed because the output in monitor units is still perfectly stable, only the output over time drifts. Hence, many physicists would like to measure with a reference detector even when using a very modern linac. The technique of placing the chamber outside the field also has drawbacks, because of the bad signal to noise ratio (for more details concerning signal to noise ratio see [12] and [13]). The disadvantage of a transmission detector is that the beam will be modified in a way. Furthermore, if the detector is linac-head mounted, the signal might drift, caused by the high temperature differences between linac head and detector and by the changing temperatures of the head itself.

In this article PTW wants to present a chamber which is not affected by these problems in small fields. The T-REF chamber is a flat, thin transmission reference chamber with a large diameter that has been optimized for a very low areal density in order to perturb the beam as little as possible. The detector is vented, air filled and has a nominal volume of 10.5 cm³. It is brought into the beam above the water surface and provides a reference signal while the beam transmits through the chamber.

The T-REF chamber is mounted to the water tank and hence is not in contact with the linac head. This prevents instabilities of the reference signal that might arise because of the elevated and non-constant temperature of the linac head. As the result of the measurement is the signal of the field chamber divided by the signal of the reference chamber, such temperature-induced drifts would deteriorate the measured curves.

This work embraces different subjects for characterizing the performance of the T-REF chamber.

- Is it trivial to bring the chamber in position? There are some tools for mounting the chamber to the water phantom that need to be checked for usability. The motor of the water tank might cause light vibrations, the impact will be studied.
- What is the maximum field size one can apply to the T-REF chamber?
- Another thing to test is the influence of the presence of the chamber. Does the T-REF chamber influence the curve measured by the field chamber? Measurements were performed with and without the chamber to test for this influence.
- Perturbations induced by the presence of the chamber should decrease when the distance between water surface and chamber is increased. We studied this distance behavior to test at which minimum distance no perturbation is deducible in the scans.
- The current measured by the T-REF chamber depends on the field size and the dose rate. It can be shown that this relation is linear.

II. Methods and Materials

In this work, we tested the T-REF chamber which can be used as reference detector in small field relative dosimetry. There are diverse reasons for introducing a new transmission measurement technique. For determining the behavior of the T-REF chamber it is important to know all the technical aspects of the chamber itself and of the used materials.

A. The detector and materials for measurements

The T-REF chamber consists of a holder for the water tank and a waterproof detector cable. The detector itself is a plane parallel air vented chamber with the following specifications:

- Nominal volume: 10.5 cm³
- Vented, waterproof (not for use in deep depths)
- Nominal response: 325 nC/Gy (at ^{60}Co free in air)
- Entrance window: 0.1 mm varnish, 0.5 mm PMMA, 0.02 mm graphite
- Total window area density: 72 mg/cm²
- Sensitive volume: radius 40.8 mm, depth 2 mm
- Guard ring width 1.1 mm
- Chamber voltage: ± (300…500) V, nominal: +400 V

The chamber is mounted on the edge of the water tank. By the use of an acrylic glass rod and a holder, the chamber can be brought in position.

The materials used to investigate the characteristics of the T-REF chamber were:

Water phantom: MP3, MP3-XS (PTW-Freiburg, Lörracher Strasse 7, 79115 Freiburg, Germany)
Two-channel electrometer: TANDEM T10011 (PTW-Freiburg)
Linac: SIEMENS Oncor (SIEMENS, Erlangen, Germany), Varian Truebeam (Varian Associates, Palo Alto, CA), Elekta Synergy (Elekta, Crawley, United Kingdom)
Field detector: microDiamond 60019 (PTW-Freiburg), Dosimetry Diode E 60017 (PTW-Freiburg)
Reference detector: T-REF chamber 34091 (PTW-Freiburg), Semiflex 0.125 cm³ 31010 (PTW-Freiburg)

The measurement of percentage depth dose curves (PDD) and profiles (TBA scans) were implemented with the MEPHYSTO mc² software of PTW.

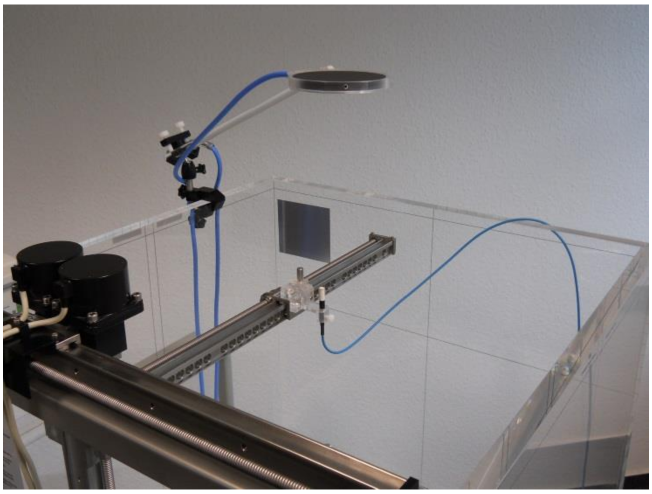
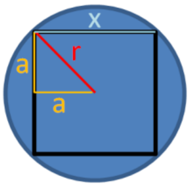


Figure 3: The T-REF chamber is mounted on the edge of the water tank and can be brought into the beam via an acrylic glass rod and holder.

B. Maximum square field size

Fieldsizes can be considered as small when they are ≤ 40 mm x 40 mm [14]. The radius of the T-REF chamber is 40.8 mm. Consequently, the maximum field size that fits on the chamber area is

$$x^2 = 4a^2 = 2r^2 = 57.7mm \times 57.7mm \quad (1)$$



The T-REF chamber is mounted above the water surface, i.e. closer to the linac source than the isocenter. Following the theorem of intersecting lines, the maximum isocenter field size can be calculated. For the minimum distance to the water surface (see chapter III.C) or DSD (detector surface distance) of 20 cm the resulting isocenter field size is 56 % larger.

C. Possible perturbation

Two main effects could lead to a perturbation of the beam. The first one is a partial build up effect together with the scattered radiation which occur from the material of the T-REF chamber and might disturb the beam a little. When in-air photons enter matter that has a higher density than air, one can observe a build-up effect, which leads to the known shape of a PDD curve, see e.g. [15]. When photons traverse the T-REF chamber, a partial build-up takes place. Due to the very low areal density, this effect is only weak. For large distances to the water surface (large DSD), the secondary electrons created in the T-REF chamber will be scattered out of the beam, hence it is expected that the partial build-up effect will not be visible if the DSD is large enough. For small DSDs, the T-REF chamber could lead to an increased surface dose. This is studied in this work by positioning the chamber in different DSDs and subsequently measuring PDDs. The expected result will be a non-measurable influence of those effects from a defined minimum DSD because the build-up radiation will be scattered out.

The second effect is the beam hardening. This effect occurs when the lower energy photons are absorbed by some material which is interposed. Because of the low areal density of the chamber, it is expected that this effect will not be visible.

Measurements with and without T-REF chamber were implemented for studying those effects.

D. The influence of inaccurate positioning and vibrations during measurement

The T-REF chamber is essentially a DAP-chamber (dose area product). Since the DAP is independent from the distance, small variations in the distance to the water surface can be tolerated and should not lead to differences in the signal.

Field sizes of small fields are mostly smaller than 4 cm x 4 cm and thus much smaller than the area of the sensitive volume of the T-REF chamber. Therefore small lateral shifts are also expected not to pose a problem. We expect that the signal is very stable during operating the MP3 water tank, despite the possible vibrations that might be introduced by the water tank motor.

III. Results and Discussion

A. Mounting

The T-REF chamber can be easily mounted on the edge of the water phantom. The acrylic glass rod with the holder enables a continuous positioning without increments. On the flat area on the top of the chamber it is possible to read the SSD value, which is projected on it by the linac. The physicist can either use the SSD projection or a ruler for positioning the chamber at the wanted distance to the water surface. Thus, the positioning is not difficult and does not require a high precision because the T-REF chamber operates on the principle of a DAP chamber. For that reason the position in z-direction is not that important and the adjusting can be done quick and easy as long as the user makes sure that the DSD is at least 20 cm.

B. Maximum square field size

The maximum field size in different DSD can be calculated following the theorem of intersecting lines (see

Table 1). For the minimum distance of the T-REF chamber (upper edge of the chamber) to the water surface (see chapter III.C) of 20 cm the space for a square field is about 56 % larger, what corresponds to a field size of 72 mm x 72 mm. When an uncertainty of positioning of ±6 mm would be included, a field size of 65 mm x 65 mm can easily be irradiated. In Figure 7 of chapter III.C it is shown that distances from20 cm on don’t result in different relative measurement curves.

Table 1 Maximum square field size following the theorem of intersecting lines

DSD [cm]	Space for length of square field [%]	Space for square field [%]	resulting length of square field [mm]
0	100.0	100	57.70
10	111.1	123.5	64.11
20	**125.0**	**156.3**	**72.12**
25	133.3	177.8	76.93
30	142.9	204.1	82.43
40	166.7	277.8	96.17
50	200	400	115.40

Thus the T-REF chamber can be placed at a distance to the water surface of e.g. 30 cm. This results in a maximum field size of about 75 mm x 75 mm. When measuring profiles (see Figure 4) for a field size of 4 cm x 4 cm, the out-of-field-fraction is 1.5 cm (37.5 % of field size) for DSD = 20 cm and 2 cm (50 % of field size) for DSD = 30 cm.

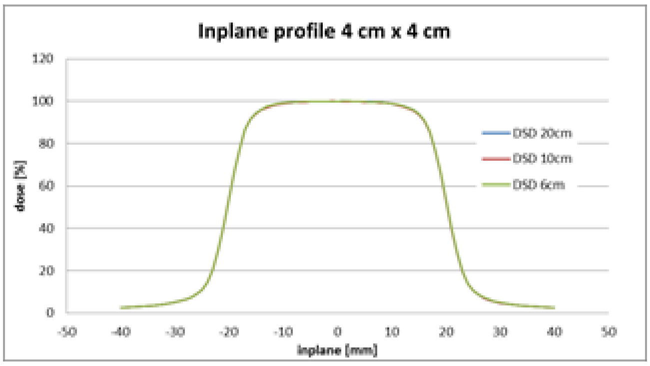


Figure 4: inplane profile 4 cm x 4 cm, 6 MV at three different DSDs (6 cm, 10 cm, 20 cm). No differences are found in the out-of-field-fraction of the curves.

In Figure 4 profile measurements for different DSDs are shown. In all cases, no influence from the guard ring or edge of the T-REF chamber is visible. Hence, the chamber can safely be used for profile measurements in small fields.

C. Perturbation from the chamber

The influence of the T-REF chamber's presence has been investigated by taking measurements with a 60019 microDiamond as field detector: first with the T-REF chamber between linac head and water surface (three different distances to the water surface: 20 cm, 22 cm and 24 cm) and secondly without presence of the T-REF chamber. A field size of 4 cm x 4 cm was chosen. Then the field signal was visualized by measuring PDDs with the focus on deviations between presence and absence of the reference chamber.

It is hard to see any differences between the different PDDs (see Figure 5). This means the perturbation is minimal and can be ignored for relative measurements, if the underlying circumstances are correct (e.g. minimum distance to water surface). The reason for the small perturbation is the very low areal density of the chamber and that the minimum distance to the water surface was maintained.

If the T-REF chamber is placed relatively close to the water surface, the partial build up can be seen in the first millimeters of the PDD because of a larger contribution of dose production. For larger DSDs, when the way through the air is long enough, these lower energy photons and secondary electrons will be scattered out of the beam. Hence for a large-enough DSD, the partial build-up effect should no longer be visible in the PDD measurements. In Figure 6 this effect can be observed. For distances from 8 cm to 18 cm there are effects, which show a light influence for the first few millimeters of the PDD.

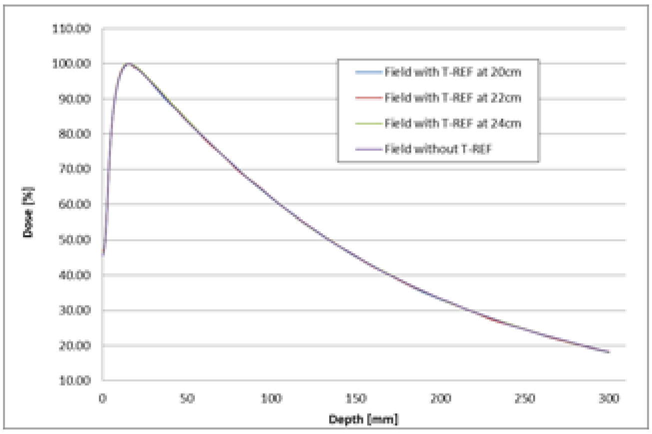


Figure 5: Field size 4 cm x4 cm, 6MV, field detector 60019. The PDDs shown here shall indicate the influence of the presence of the T-REF chamber. The curves are smoothed and are not divided by the reference signal. It is clear that the influence is very small. The relative depth dose curves of the three different DSDs of the T-REF chamber and one where a Semiflex 0.125 cm³ was used as reference lie very well on top of each other. The positioning of the Semiflex chamber followed the normal procedure of placing it into a corner of the field.

Above 20 cm no influence is observable in the Data (see Figure 7). This leads to the fact that the physicist has a free choice in positioning the T-REF chamber, as long as he respects the minimum distance to the water surface of 20 cm.

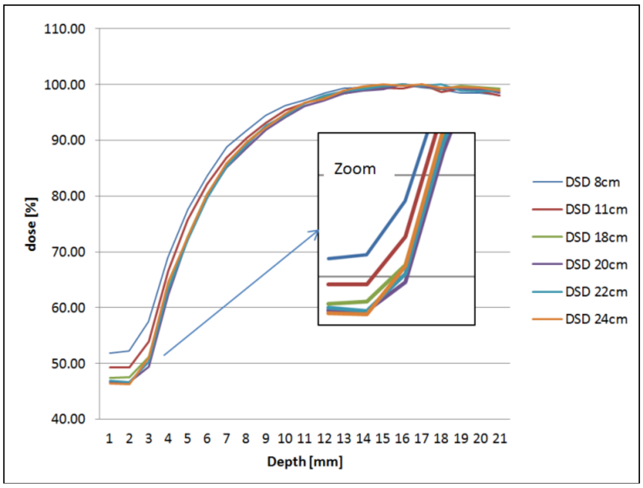


Figure 6: PDDs measured in 4 cm x4 cm, SIEMENS Oncor 6MV. The distance-to-water-dependence is clearly visible in the onset of the PDDs.

For larger distances of the T-REF chamber larger fields can be applied. In Table 1 the factor of field size increase can be seen. For a DSD of 40 cm, which is close to the linac head, field sizes of almost 10 cm x 10 cm can be applied. But for these field sizes a standard Semiflex chamber in the corner of the field can be sufficient, whereby the signal to noise ratio would be slightly worse.

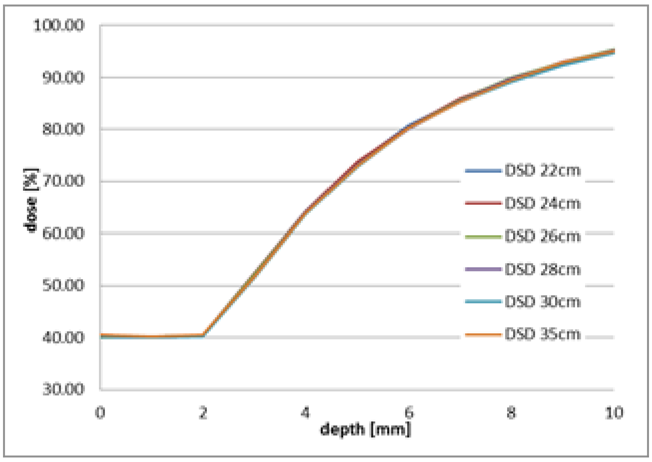


Figure 7: 2 cm x 2 cm, Electa Synergy 6MV, Different distances from minimum to 35 cm

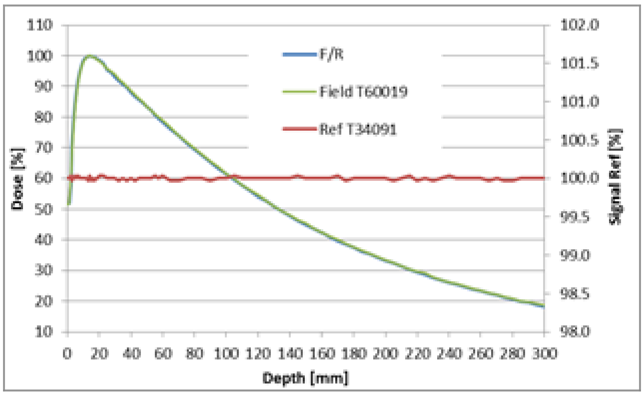


Figure 9: PDD measurements, 4 cm x 4 cm, field detector 60019, Varian Truebeam 6MV: a T-REF chamber used as reference chamber. Measuring time per data point 0.5s.

D. Different approaches for measuring the reference signal compared with the T-REF chamber

For the standard technique of measuring the reference signal, a thimble chamber, here the Semiflex 0.125 cm² 31010 is placed in the corner of the field. In **Error! Reference source not found.** the relative noise of the reference measurement in a 4 cm x 4 cm field is easy to see because of a high resolution of the axis from 98 % to 102 %. When comparing this measurement with one of the T-REF chamber in Figure 9, which was placed in the beam as a transmission chamber, the difference in the noise becomes clear. In the PDDs there are no observable differences. This excellent signal to noise ratio is one of the advantages of the T-REF chamber. It follows from Figure 9 that the vibrations caused by the motor of the water phantom do not influence the reference signal.

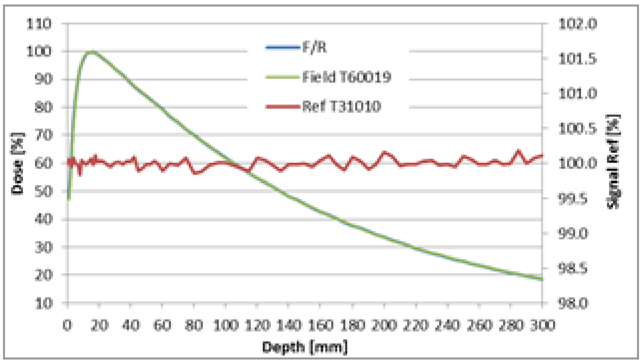


Figure 8: PDD measurements, 4 cm x 4 cm, field detector 60019, Varian Truebeam 6MV: a Semiflex 0.125 cm³ used as reference chamber. Measuring time per data point 0.5s.

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E. The current magnitude of the reference signal

One further investigation was whether and how the measuring current of the T-REF chamber depends on the field size and on the dose rate. Because the T-REF chamber measures one value over the whole area, one could assume that the relation "the bigger the field, the larger the measurement current" is linear with the field area (in cm²).

Here for 300 MU/min (approx. 3 Gy/min) and 6MV the following field sizes were tested: 1x1, 2x2, 3x3 and 4x4 [cm x cm]. As can be seen from the data table (see Figure 10), the signal indeed increased linearly with the field size. From these data points the other dose rates and field sizes were calculated. The two-channel electrometer of PTW, TANDEM, has three range settings: LOW, MEDIUM and HIGH. They are defined as follows:

Table 2: Range setting of PTW TANDEM

Range	[A]
LOW	5.0E-12 … 1.0E-9
MEDIUM	50.0E-12 … 10.0E-9
HIGH	500.0E-12 … 100.0E-9

dose rate [MU/Min]	Length of quadratic field [cm] 0.3	0.5	1	2
100	2.8E-12	7.7E-12	30.9E-12	123.7E-12
200	5.6E-12	15.5E-12	61.9E-12	247.5E-12
300	8.4E-12	23.2E-12	*92.8E-12*	*371.2E-12*
400	11.1E-12	30.9E-12	123.7E-12	494.9E-12
500	13.9E-12	38.7E-12	154.7E-12	618.7E-12
600	16.7E-12	46.4E-12	185.6E-12	742.4E-12
1000	27.8E-12	77.3E-12	309.3E-12	1.2E-9
1200	33.4E-12	92.8E-12	371.2E-12	1.5E-9
1400	39.0E-12	108.3E-12	433.1E-12	1.7E-9
2400	66.8E-12	185.6E-12	742.4E-12	3.0E-9

	3	4	5	6
100	289.2E-12	533.7E-12	773.3E-12	1.1E-9
200	578.5E-12	1.1E-9	1.5E-9	2.2E-9
300	*867.7E-12*	*1.6E-9*	2.3E-9	3.3E-9
400	1.2E-9	2.1E-9	3.1E-9	4.5E-9
500	1.4E-9	2.7E-9	3.9E-9	5.6E-9
600	1.7E-9	3.2E-9	4.6E-9	6.7E-9
1000	2.9E-9	5.3E-9	7.7E-9	11.1E-9
1200	3.5E-9	6.4E-9	9.3E-9	13.4E-9
1400	4.0E-9	7.5E-9	10.8E-9	15.6E-9
2400	6.9E-9	12.8E-9	18.6E-9	26.7E-9

LOW	MEDIUM	HIGH

Figure 10: Currents of T-REF chamber dependent of field size and dose rate in [A]

For small fields up to 2 cm x 2 cm and dose rates up to 600 MU/min the range LOW can be kept as default. For larger field sized and higher dose rates MEDIUM will be more suitable. If the user is not sure about the settings the indication for the ideal range can be watched in the PTW-tbaScan interface of MEPHYSTO mc² software. If the signal bar is filled out by 2/3 the setting is perfect. If it is lower than 1/3 or 1/4 the user might set a lower range and vice versa.

IV. Conclusions

In this work, the new PTW T-REF chamber was characterized in a clinical environment. This chamber provides a solution to the problem of where to put the reference chamber for small field PDD and profile measurements. The chamber proved to be fast and easy to mount, and as long as the minimum distance of 20 cm above the water surface was maintained, no perturbation due to the use of the transmission chamber could be seen in the curves measured for this work, neither for PDDs, nor for profiles. The range of usable field sizes was provided and covers the entire range of use for small field measurements. No influence from vibrations from the motors of the water phantom could be deduced in the measurements, as was expected for a DAP-type reference detector. Indeed, the signal to noise ratio of the T-REF chamber proved to be excellent, exceeding that of a classical Semiflex 0.125 cm³ chamber in the corner of the irradiation field. Because the chamber is mounted to the water phantom and not to the linac head, there are no temperature drifts which might influence the reference signal. Care must be taken by the user to correctly set the range of the electrometer of the channel to be used with the T-REF chamber. An exemplary table was provided which shows the range setting for a TANDEM electrometer in use at field sizes of 0.3 cm x 0.3 cm up to 6 cm x 6 cm.

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Conflict of Interest Statement

The Author is employee of PTW-Freiburg.

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