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Short Communication

# Measurement of absorbed dose in water in brachytherapy

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## Abstract

*Introduction:* The most commonly used method for measuring the activity of sources in brachytherapy involves well chambers, which are utilized to measure air kerma. Brachytherapy centers are required to employ the TG-43 algorithm, which calculates the dose distribution in water. Transitioning from air to water introduces uncertainties. The objective of this study is to develop a new method for measuring the absorbed dose in water for $^{192}$Ir radiation.

*Material and Methods:* A prototype ionization chamber was used in this study. To determine the absorbed dose in water measured by this chamber, the definition of absorbed dose in water was applied directly. Perturbation factors were calculated using Monte Carlo simulations, while correction factors were derived from measurements taken with the ionization chamber. A water phantom was created, along with a positioning system for the ionization chamber and a holder for the source. Corrections were calculated for polarization, recombination, saturation, and the effects of pressure and temperature on the chamber signal were taken into account. Measurements were performed at the position of the maximum chamber signal, determined before each measurement, and repeated for various air kerma values and different sources.

*Results:* The measurement results in water were compared to those obtained from the TG-43 algorithm. Results indicate a combined measurement uncertainty of 1.26%, representing a significant improvement over the well chamber measurements.

*Conclusion:* Preliminary results indicate the potential for improving dosimetric accuracy in brachytherapy. By using values for absorbed dose in water, uncertainties associated with converting air kerma to dose distribution in water can be eliminated.

**Keywords**: brachytherapy; dosimetry; HDR; ionization chamber.

## Introduction

The current dosimetric standard in brachytherapy involves the use of ionization well chambers[1] to measure air kerma strength. Farmer-type[1] chambers can also be used interchangeably, but such measurements are more challenging to perform and calculate. The easiest measurement method is definitely the use of well chambers. Regardless of which method we choose, it will be an air measurement yielding the air kerma value. We must remember that ionization chambers are also calibrated in air for radiation other than iridium. This means we are using a chamber in a radiation field different from the one it was calibrated for. The measurement result, which is the value of air kerma strength, is entered by medical physicists into the treatment planning system (TPS). These systems implement a formula developed by the TG-43 group.[2]

$$\dot{D}(r,\theta) = S_k \Lambda \frac{G(r,\theta)}{G(r_0,\theta_0)} g(r) F(r,\theta) \quad \text{Eq. 1}$$

where:
r – distance from the origin to point P (cm);
Θ – angle between vector r and long axis of the source;
$\Theta_0$ – defines the transversal plane (π/2);
$S_K$ – air kerma strength ($mGy \cdot m^2 \cdot h^{-1}$);
Λ – dose rate constant in water;
G(r, Θ) – geometry function;
g(r) – radial dose function;
F(r, Θ) – anisotropy function.



Authors' contribution: A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of the article.

According to this formula, treatment planning systems calculate the radiation dose distribution in water. In short, measurements are performed in air, while calculations are made for water. Transitioning from one medium to another generates uncertainties, as a coefficient must be used to enable this. This coefficient is the dose rate constant, Λ. Unfortunately, it is not defined unambiguously.[3] The literature contains various values for this coefficient as well as different methods[4,5] for its determination. This study aims to develop a new method for measuring the absorbed dose in water for $^{192}$Ir radiation. This will enhance the accuracy of measurements in brachytherapy and consequently reduce the uncertainty in dose delivery during patient treatment.

## Material and Methods

A prototype ionization chamber was used for measurements, which had not been calibrated in water for iridium radiation. Consequently, it is not possible to convert the chamber signal using a calibration factor to determine the measured dose. To ascertain the dose corresponding to the measured signal, the definition of absorbed dose was applied directly. It is important to note that the chamber used in the experiment is designed as a volume of air surrounded by a graphite wall with a graphite inner electrode. Placing such a device in a photon beam will generate disturbances and alter the flow of photons at transitions between different materials. Therefore, each of these disturbances must be accounted for in the formula for calculating the absorbed dose in water.[5]

$$\dot{D}_w = \frac{I}{m_{air}} \cdot \left(\frac{\overline{W}}{e}\right)_{air} \cdot \bar{s}_{c,air} \cdot (\mu_{en}/\rho)_{w,c} \cdot \Psi_{w,c} \cdot \beta_{w,c} \cdot \Pi_{k_i} \quad \text{Eq.2}$$

where:
I – ionization current measured in the volume V of the ionization chamber gas,
$M_{air}$ – air mass in the ionization chamber cavity,
W/e – average electron energy required to generate an ion pair in the air,
$s_{c,air}$ – average mass stopping power between air and graphite,
$(\mu_{en}/\rho)_{w,c}$ – average mass energy absorption coefficient between water and graphite,
$\Psi_{w,c}$ – difference between energy fluence in water and graphite,
$\beta_{w,c}$ – coefficient relating the absorbed dose in water to the collision kerma in graphite,
$\Pi_k$ – product of correction coefficients taking into account the actual measurement conditions.

## Perturbation coefficients

The perturbation coefficients in **Equation 2** are determined using Monte Carlo simulation. The product of these coefficients gives one value of the general perturbation coefficient f. The EGS code was used for simulation in this work. An ionization chamber was introduced to the simulation program along with a mapped water phantom, handles, an applicator into which the source is inserted, and the source itself from the Bravos therapeutic device. All materials that the above research equipment is composed of were introduced to the simulation.

## Correction factors

The mass of air in the ionization chamber was determined using computed tomography. The corrections needed to calculate the absorbed dose include a saturation correction and a correction for air humidity. Thus, the formula for the absorbed dose in water[8,9] simplifies to:

$$D_w = \frac{I_{corr}}{Vol_{cav} \cdot \rho_{air_0}} \cdot \frac{\overline{W}_{air}}{e} \cdot f \cdot k_{sat} \cdot k_h \quad \text{Eq. 3}$$

where:
$I_{corr}$ – corrected (for temperature and pressure conditions) ionization current,
$Vol_{cav}$ – volume of the ionization chamber cavity,
$\rho_{air}$ – density of dry air under standard conditions,
$W_{air/e}$ – average electron energy needed to produce a pair of ions in air,
$f$ – perturbation factor,
$k_{sat}$ – correction factor for saturation,
$k_h$ - correction factor for humidity.

During the measurements, the chamber signal was continuously corrected for the influence of pressure and temperature according to the formula:

$$k_{pT} = \frac{273.15+T}{293.15} \cdot \frac{1013.25}{p} \quad \text{Eq. 4}$$

where:
T, p – temperature and air pressure during measurement.

During the measurements, the correction factor for polarization, $k_{pol}$, was determined.[9] The use of this correction factor is not mandatory, as it is often very close to one; however, it serves as a good indicator of the proper construction of the ionization chamber. It is advisable to use it for new ionization chambers, as in this case.

$$k_{pol} = \frac{|I_+|+|I_-|}{2I} \quad \text{Eq.5}$$

where:
$I_+$ $I_-$ – ionization current measured for a given voltage polarity.

The correction factor for recombination and saturation was determined[10] according to [Andreo et al., 2017].[11]

$$\mathrm{k_{rec}} \approx 1 + \frac{\mathrm{A}}{|\mathrm{V}|} + \frac{\mathrm{B}}{|\mathrm{V}|^2}|\mathrm{I_V}| \quad \text{Eq. 6}$$

where:
V – set voltage,
$I_V$ – current at a given voltage,
A, B – proportionality coefficients.
The correction for air humidity is $k_h = 0.997$ when measurements are taken between 20% and 80% humidity.[12]

## Measuring equipment

The ionization chamber (**Figure 1**) designed from scratch at the Central Office of Measures was used in the work. It was the Farmer-type graphite chamber with an active volume of 0.524 $cm^3$ with a central electrode.

To enable measurements of the absorbed dose in water, a water phantom was constructed with a special positioning system for the source holder and the ionization chamber holder (**Figure 2**). The chamber is placed in a waterproof casing. The holder for the $^{192}Ir$ source is designed for use with a lung applicator of 5 French diameter, which is approximately 1.67 mm. The phantom was continuously improved to accurately determine the distance between the source and the ionization chamber.

The chamber was connected to a Keithley electrometer. A thermometer and barometer connected to the control software for the chamber and electrometer allowed for real-time correction of the signal for pressure and temperature. Measurements were performed using the Bravos therapeutic device, with the source moving in a Varian lung applicator.

The design of the phantom allows it to be used with devices and applicators from other manufacturers, provided that the diameter of the applicator is compatible with the holder mounted in the phantom (**Figure 3**).

## Measurement procedure

Before each measurement, the calibration of the source position and the inactive source marker was performed. The Bravos[13] device allows for such calibration with an accuracy of 0.1 mm. The software controlling the electrometer was set up to collect between 3 and 5 series of measurements during a single source withdrawal. Each series consisted of 10 measurements. Thus, for one source withdrawal, between 30 and 50 ten-second measurements of current and charge were collected. After changing the voltage, polarization, or distance of the chamber from the source, the procedure was repeated. The averaged measurement results had the chamber's own current subtracted, which was recorded each time before and after the measurement. Measurement sessions often lasted all day, necessitating corrections to the obtained results due to the decay of the radioactive source throughout the day.

$$k_t = exp\left[\frac{ln2}{T_{1/2}}(t - t_0)\right] \qquad \text{Eq. 7}$$

where:
$T_{1/2}$ – radioactive halftime,
$t_0$ – reference date,
t – measuring time.

**Figure 1. Prototype ionization chamber.**

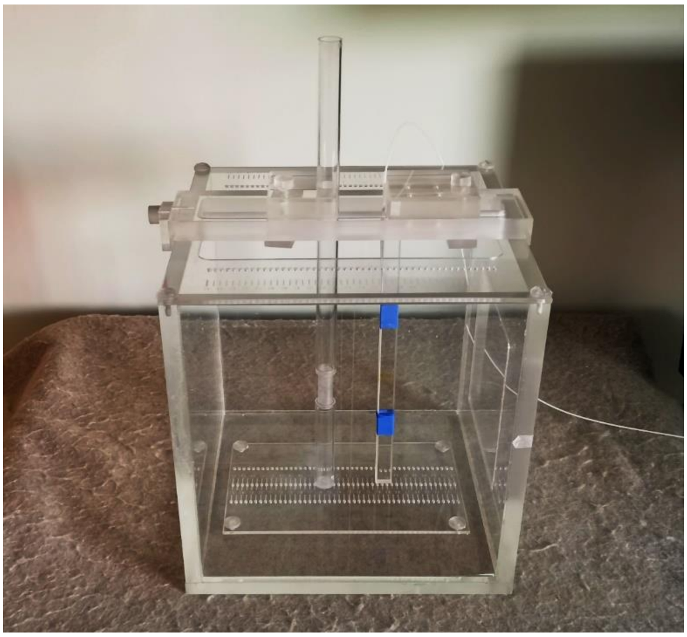

**Figure 2. Water phantom with holder system for chamber and source.**

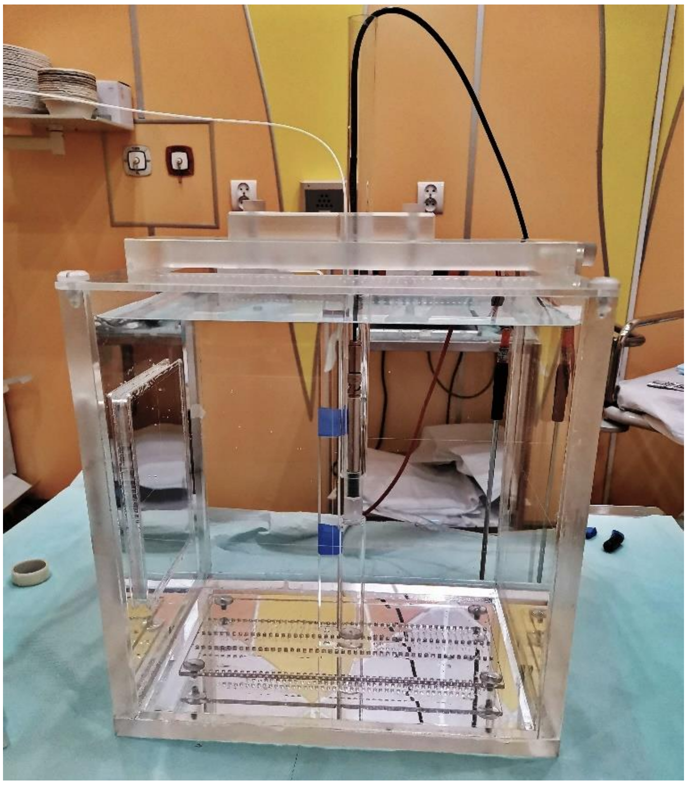

**Figure 3. Water-filled phantom with an ionization chamber and lung applicator.**

The measurement setup was arranged so that the active part was positioned in the center of the active length of the source. However, the point of maximum signal was determined experimentally each time. Measurements were conducted for different activities of the $^{192}$Ir source as well as for various iridium sources from the same manufacturer, which are typically replaced every three months. To confirm the accuracy of the calculations in the treatment planning system, theoretical calculations were performed according to **Equation 1** of the TG-43 algorithm (**Table 1**). The theoretical and measurement points are located 1.17 cm from the source in a plane perpendicular to it. Given the small measurement distance, it is necessary to account for the linear structure of the isotope. Since the difference between theoretical calculations and measured values is 0.04%, the TPS calculations were accepted as correct.

## Results

Assuming that the energy required to create an ion pair is 33.97 [J/C], considering an air density of 1.2045 kg/m³, and accounting for the previously described corrections, we can complete the formula in **Equation 3** for the absorbed dose in water. We will then obtain data as shown in **Table 2**.

By inserting the measured current value from the measurement into **Table 2**, we obtain the absorbed dose in water. Similar calculations were performed for different source activities. The averaged results from the water measurements were compared to the dose values calculated in the BrachyVision treatment planning system.

The measurement results in **Table 3** have been recalculated for an activity of 10 Ci, as this value is used to generate the dose distribution in water within the BrachyVision treatment planning system.

## Discussion

The results presented in this study are preliminary, as the development of the measurement procedure is not yet complete. Nevertheless, a reduction in measurement uncertainty to 1.26% compared to the well chamber (approximately 3%) can already be observed. The magnitude of the uncertainty and the difference between the measurement and the treatment planning system (**Table 3**) are influenced by the inaccurate positioning of the source. During the data collection for this work, it became evident that the increased scatter of values around the mean was caused by the source not always stopping in the same position. Despite calibrating the source's resting position before each measurement, the source sometimes stopped in a different location. This difference is on the order of 0.1 mm, which is significant enough to notice variations in measurements. On the other hand, this is compliant with regulations, as it meets the required ±2 mm difference in source positioning.[14]

**Table 1. Comparison of calculations according to Tg-43 from the treatment planning system with theoretical calculations.**

| | Value | Uncertainty [%] |
|---|---|---|
| TPS $D_w$ [cGy] according to TG-43 | 100.04 | 1.6 |
| Theoretical $D_w$ [cGy] according to TG-43 | 100 | 0.2 |
| Difference between TPS and TG-43 theoretical | 0.04% | |

**Table 2. Data table for reading absorbed dose in water. Sample current value.**

| Symbol | Value | Uncertainty A [%] | Uncertainty B [%] |
|---|---|---|---|
| f | 1.1264 | 0.5 | |
| $I_{corr}$ [pA] | 1000 | 1.14 | 0.1 |
| $D_w$ [mGy/s] | 60.47 | 1.26 | |

**Table 3. Difference between the absorbed dose value: measured and the value from the treatment planning system.**

| | Value | Uncertainty [%] |
|---|---|---|
| Average measured $D_w$ [mGy/s] | 90.15 | 1.26 |
| TPS $D_w$ [mGy/s] according TG-43 | 92.63 | 1.6 |
| Difference between measurement and TPS | 2.27% | |

## Conclusions

From the above considerations, it follows that utilizing the proposed method for measuring the absorbed dose in water[15] directly in $^{192}$Ir radiation can reduce the final measurement uncertainty. Furthermore, such a measurement may eliminate the uncertainty associated with determining air kerma and the uncertainty related to calculating the dose rate constant.

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## Editor's comment

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