JULY 12–16 2020 VIRTUAL
JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

Plastic Scintillation Detector Calibration Procedure for Brachytherapy in vivo Dosimetry

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INTRODUCTION

Currently we have an exhaustive knowledge of the uncertainty associated with different brachytherapy treatments. However, since this modality is usually hypofractionated, characterized by high dose gradients, and in which many steps are performed manually, it is advisable to have tools that allow us to detect deviations from the planned doses during the treatment.

Of the different in vivo dosimetry modalities, one that stands out for its low angular, temperature and energy dependence, its high sensitivity and its small size, among others, is plastic scintillation dosimetry.

In order to calibrate robustly such type of detectors in small and practical phantoms it must be considered that the Ir-192 spectrum in a certain location of a phantom depends on its dimensions and material. As the spectrum affects directly the detector response, it is necessary to perform a Monte Carlo simulation to obtain the corresponding PSD calibration factor.

AIM

To stablish a robust plastic scintillation detector (PSD) calibration procedure for brachytherapy *in vivo* dosimetry with a Farmer chamber in a new designed PMMA phantom:

- obtain via Monte Carlo the k_{QQ0} factor to convert the Farmer ionization measured in the new PMMA phantom to absorbed dose in a full scatter geometry, as recommended in AAPM TG43 report, using the IAEA TRS398 formalism.
- Empirically verify some of the PENELOPE/PenEasy simulations

METHOD

- A PMMA phantom was constructed to calibrate in a robust manner in vivo PSD probes from NU-RISE (Aveiro, Portugal). The phantom incorporates 4 holes located in the phantom periphery for Ir-192 source insertion through needles of 1.22 mm internal diameter and one central accessory to alternate PSD and PTW (Freiburg,Germany) PMMA Farmer ionization chamber (see Figure 1).
- D_w and D_{air} were computed with PENELOPE/penEasy using an Ir-192 source model in both geometries: PMMA phantom and water sphere of R=40 cm to obtain a k_{QQ0} quality factor. Through IAEA TRS-398 formalism, ionization measured in the PMMA phantom with the Farmer chamber calibrated in a Co-60 beam allows absorbed dose to water determination in full scatter conditions.
- D_{air} simulations were performed with a model[1] of the PTW PMMA Farmer chamber averaging the absorbed dose in the air cavity (see Figure 2) and D_w values are obtained by substitution of the Farmer chamber by a very small water sphere as detector.
- Experimental validation of the Monte Carlo D_{air} ratios obtained were performed with a PTW Farmer ionization chamber in the PMMA phantom and in a pseudo AAPM TG43 geometry using a commercial scanning water phantom with a positioning accessory replicating the geometry of the PMMA phantom.

RESULTS

Following IAEA TRS398 formalism the absorbed dose to water in the PMMA phantom using an Ir-192 source is:

$$D_{w,Ir\text{-}192}^{PMMA\ phantom} = N_{D,w}^{Co\text{-}60} \cdot M^{PMMA\ phantom} \cdot k_{Ir\text{-}192}^{PMMA\ phantom}$$

Where $N_{D,w}^{Co\text{-}60}$ is the Farmer chamber Co-60 calibration factor, $M^{PMMA\ phantom}$ is the corrected ionization measured in the PMMA phantom and $k_{Ir\text{-}192}^{PMMA\ phantom}$ factor has been estimated by Monte Carlo from:

$$k_{Ir\text{-}192}^{PMMA\ phantom} = ([D_w/D_{air}]_{Ir\text{-}192}^{PMMA\ phantom})/([D_w/D_{air}]_{Co\text{-}60}^{IAEA\ TRS398\ geometry})$$

To obtain absorbed dose to water in a full scatter AAPM TG43 geometry the following conversion factor has been computed with penEasy:

$$[D_{w,Ir\text{-}192}^{AAPM\ TG\text{-}43} / D_{w,Ir\text{-}192}^{PMMAphantiom}] = 1.138 \pm 1.7\ \%\ \text{with}\ k=1.$$

Rearranging terms:

$$D_{w,Ir\text{-}192}^{AAPM\ TG\text{-}43} = N_{D,w} \cdot M^{PMMA\ phantom} \cdot k_{QQ0}$$

Where $k_{QQ0} = [D_w^{AAPM\ TG\text{-}43}/D_{air}^{PMMA\ phantiom}]_{Ir\text{-}192} / [D_w/D_{air}]_{Co\text{-}60}^{IAEA\ TRS398\ geometry}$

The obtained value for this quotient of water/air ratios is 1.108± 1.9 % (k=1).

The Monte Carlo calculated D_{air} ratio for both geometries is:

$$(D_{air}^{AAPM\ TG\text{-}43}/D_{air}^{PMMA}) = 1.086 \pm 1.8\ \%\ \text{with}\ k=1.$$

This ratio was verified experimentally obtaining the following result:

$(M_1/M_2) = 1.094 \pm 2.1$ % with k=1.

Monte Carlo and ionization measurement uncertainties are detailed in Table 1.

Figure 1. PMMA phantom showing the 4 needles in the periphery for Ir-192 source insertion and central accessories to alternate PSD and PTW PMMA Farmer ionization chamber.

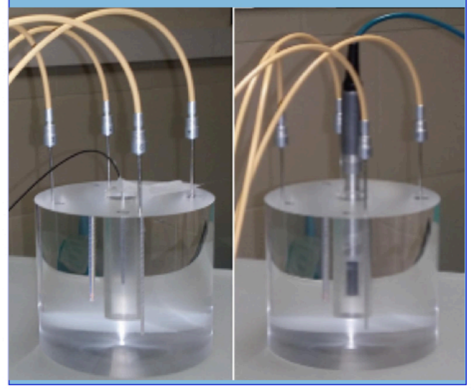

Figure 2. PENELOPE/PenEasy Dair simulation geometry of the PMMA phantom showing the PTW PMMA Farmer ionization chamber cavity and the Ir-192 source model on the left needle.

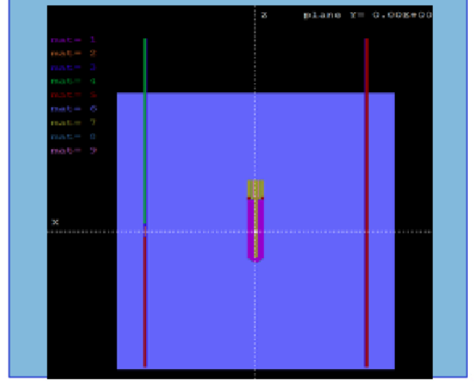

Table 1. Estimated uncertainties of the Farmer chamber ionization measurements and of the Monte Carlo PENELOPE/PenEasy simulations.

Uncertainty component	Relative propagated uncertainty	
Uncertainty component	Type A[%]	Type B[%]
$N_{D,w}$ calibration factor		0.6
Electrometer calibration		0.1
Clinic Farmer measurement reproducibility	0.5	
$k_s \cdot k_{pol} \cdot k_{TP}$		0.2
Source positioning inside 5F steel needles		1.6
Mechanical drilling of needle holes		1.0
$(s_{w,air} \cdot p \cdot W_{air})_{Co\text{-}60}$ IAEA TRS398 [2]		0.8
Clinic Monte Carlo [3]		1.6
PMMA Phantom composition, density [4]		0.6
Farmer chamber materials composition		0.05
Farmer materials cross sections		0.07
Air composition		0.05
Air cross sections [5]		0.05
Total dose uncertainty	2.8	

CONCLUSIONS

Instead of using an indirect calibration through air kerma strength (S_K) to absorbed dose to water (D_w) transference via AAPM TG43, a faster, robust and direct D_w measurement procedure was developed for PSD calibration.

The discrepancies between measured ionization ratio and Monte Carlo obtained D_{air} ratios in both geometries are well within the combined experimental and Monte Carlo uncertainties (±2.8% with k=1).

The main advantage of this small PMMA phantom is that PSD direct calibration can be performed without using the water scanning phantom.

The full procedure takes less than 10 min and can be performed before each brachytherapy treatment.

If an indirect calibration is done, an air kerma strength measurement with well type chamber is needed to obtain absorbed dose to water through the AAPM TG43 formulism. The uncertainties of this indirect calibration has been estimated (± 4.3% with k=1) and are higher than the direct calibration method proposed in the present work.

REFERENCES

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ACKNOWLEDGEMENTS

The author thanks Carles Gomà for his model of the PTW PMMA Farmer ionization chamber.

The author also thanks Joana Melo and Luis Moutinho from NU-RISE (Aveiro, Portugal) for providing the in vivo dosimetry equipment and the PSD probes.

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